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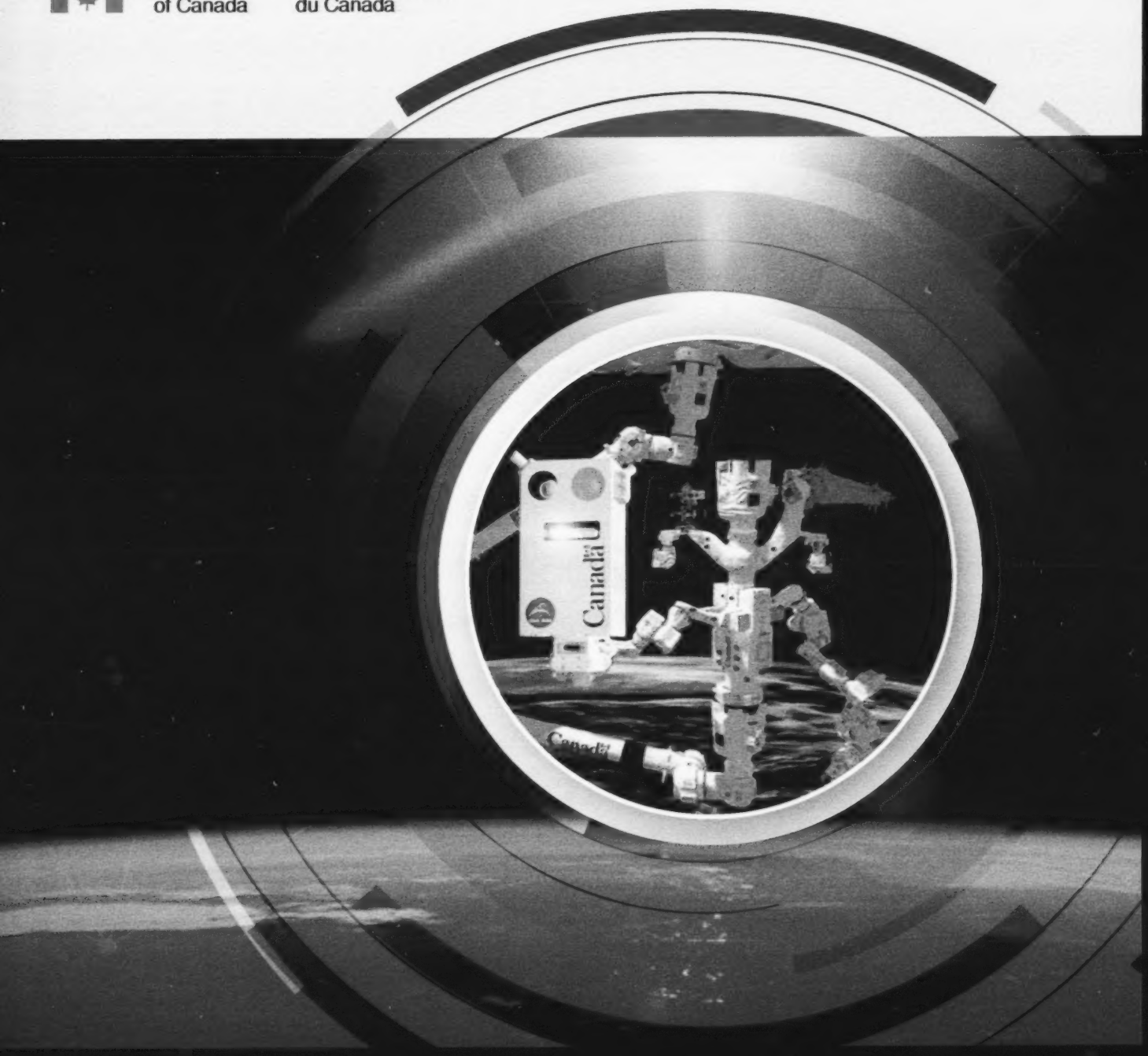

Patents in Space

Highlighting Innovation in the Canadian Space Sector

Canada

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The Patents in Space report is a joint effort between the Canadian Intellectual Property Office (CIPO) and the Canadian Space Agency (CSA). The report endeavors to develop a more comprehensive view of patenting in the Canadian space sector and outlines a refined search methodology that can be replicated by other space-faring countries.

CIPO leveraged its corporate expertise to develop a comprehensive patent search strategy with the help of mechanical and electrical patent examiners. Patent analyses, econometric analyses, as well as data visualizations by sector of space activity were also provided by CIPO.

CSA provided space-specific data and information, methodological support, and economic trend assessments through expertise in a number of areas namely: economic analysis and research, space science and technology engineering, and intellectual property management in the space sector.

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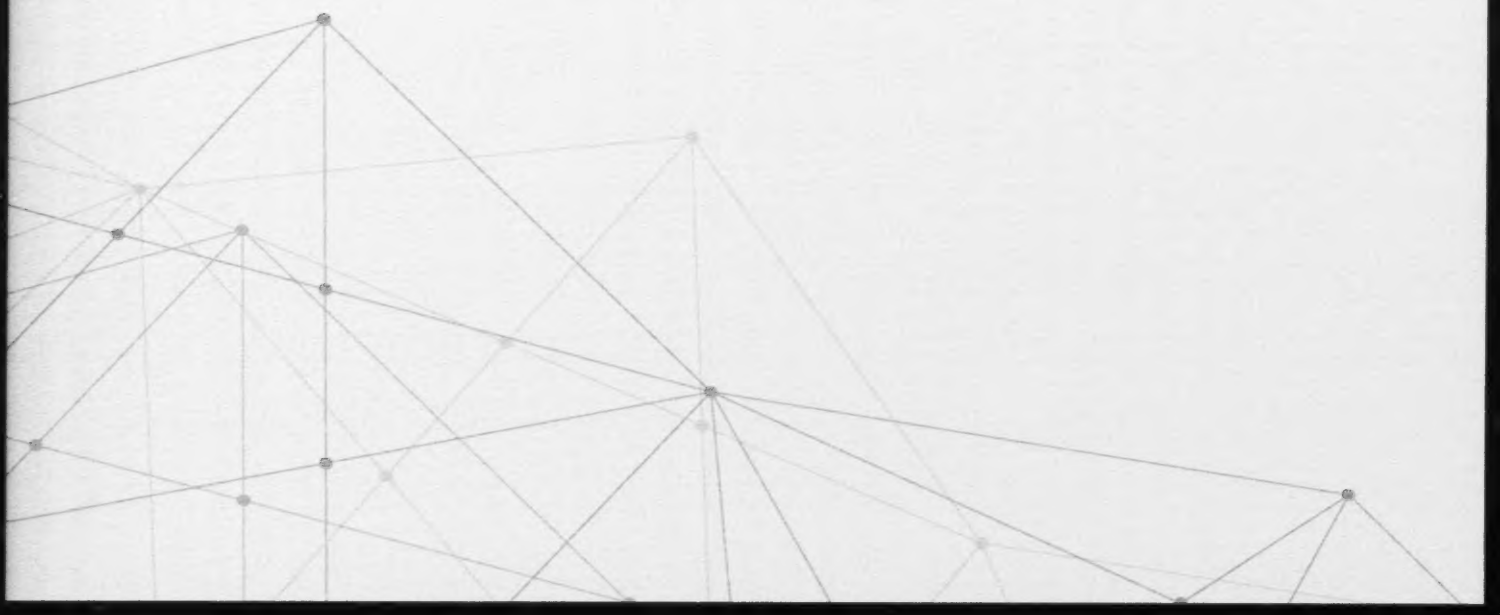

EXECUTIVE SUMMARY

Measuring innovation is a challenging task. However, patent data is a good starting point to address this challenge as it provides important information on the specific technical knowledge embedded within inventions. This report, a collaborative effort by the CSA and CIPO, shines a light onto patent activity in the Canadian space sector.

In broad terms, this report is the culmination of a complete literature review, a compilation of organization specific data from the CSA's annual *State of the Canadian Space Sector* survey and a robust patent search strategy.

This report shows that global patent filing in the space sector has consistently grown over the last 40 years, with the number of annual patented inventions now more than 20 times greater than in 1978, rising from 320 to 6,419. The report also reveals that Canada has more influence internationally than its size would suggest, potentially signalling a technological advantage for its space sector.

This report highlights the importance of small and medium sized enterprises (SMEs) for innovation in the Canadian space sector. SMEs account for 83% of organizations with patented inventions and are responsible for 83% of all patented inventions in the sector. SMEs are also responsible for 30% of the revenue and 30% of the expenditures spent on research and development (R&D). Looking at value-chain segments, between 2000 and 2015, Canadian patent activity in the downstream value chain component has increased from 23% to 60% and follows the Canadian and international shift towards private sector space activity and revenues.

Using the CSA's annual space survey data of space sector organizations in combination with patent data, this report shows multiple positive economic relationships. These relationships include: a relationship between the number of R&D employees per organization and annual patented inventions, a relationship between revenue and R&D expenditures, a relationship between revenue and R&D employees, a relationship between R&D expenditures and R&D employees and a relationship between R&D expenditures and annual patent inventions.

This report uses visualizations to present data in a comprehensive fashion. Landscape maps are one of these visualizations and are used to help identify keywords, International Patent Classification codes and key technologies being developed in the Canadian space sector. In this report, these maps are broken down by value-chain segment and sector of activity within the Canadian space sector.

Overall, this report helps to describe the areas of activity and key fields of research found in the Canadian space sector. The information contained in this report can be used as a launching pad to pursue more in-depth research into targeted space technologies.

INTRODUCTION

Fewer words can invoke such awe and curiosity as space. We imagine so many possibilities and then we set out to make them happen, solving some of the most profound problems in science. Yet, the space sector is still only in its infancy, with the first human spacecraft reaching the edge of our solar system only in 2012. We are a long way from understanding the universe and all of its mysteries.

The space sector is highly innovative and generates products and services that benefit Canadians every day. Worldwide, the space sector has brought us the following: long-distance telecommunications, solar energy, memory foam, anti-corrosion coating, the insulin pump, cochlear implants, improved screening for cardiovascular disease and breast cancer, water filters, scratch resistant lenses and of course Velcro.[i] The space sector is an important part of the Canadian economy, accounting for $5.5 billion (CDN) in revenues and nearly 10,000 Canadian jobs in 2016.

Hermes satellite (Credit: Canadian Space Agency)

Canadian ingenuity has and continues to be important in the development of revolutionary new technologies for space exploration. The Canadarm, which made its debut in 1981 and was retired in 2011, became synonymous with Canada's space program. Presently the Canadarm2 is operating on the International Space Station (ISS). Additionally, in the last decades, Canadian researchers have contributed to the leading edge of space exploration in many ways. For example, in 1971, Canada began work with NASA on the development of an experimental Communications Technology Satellite (CTS), known as Hermes. The satellite, which was launched in 1976, was the most powerful communications satellite at that time. Another example of Canadian ingenuity in space technology is the microgravity isolation mount, which uses magnetic levitation to protect fragile experiments from vibrations in low gravity. Built for the CSA's Microgravity Science Program, it was first used aboard the Russian Priroda Space Module and is now in its third generation. More recently, researchers at the University of Guelph have been working on techniques that could one day allow for the growth of crops on the moon or Mars.[ii]

While patents in the space sector are not as prevalent as other manufacturing and technology sectors, they have become increasingly important, with worldwide space patents almost quadrupling between 1991 and 2011.[5] A comprehensive view of patent activity in the Canadian space industry does not currently exist. The report at hand, a collaborative effort between the CSA and CIPO, shines a light onto this important and interesting innovation area. In broad terms, this report is the culmination of a complete literature review, a compilation of organization-specific information, an extensive and targeted patent search strategy, and finally a robust examination of the search strategy to ensure that it produces reliable results.

The remainder of the report is structured as follows. The next section discusses patents as a metric for innovation. The third section presents the development of the patent search strategy. The fourth section looks at the space sector in Canada, providing a view of the structure of the sector and its economic impact. The fifth section dives deeper into the patent data, following the economic structure of the space sector. The final section provides some conclusions.

PATENTS AND INNOVATION

Measuring innovation is a difficult task. A universal indicator for measuring innovative activity does not currently exist. However, patent activity has been identified as a good proxy measure for innovative activity and, internationally, the space industry has recognized the annual production of patents as a primary indicator for measuring innovation.[iv] In addition, it was noted in the report *The Use of Intellectual Property Rights and Innovation by Manufacturing Firms in Canada* that world-first innovators patent more frequently and firms that patent infrequently tend to be imitators.[v] In addition, the study finds that firms that protect their intellectual property (IP) are more likely to increase their profits than those which do not. Moreover, SMEs that patent are more likely to be high-growth firms and are more likely to export, which is important for success.[vi] These conclusions are reinforced by a Canadian study that noted that firms that are aggressive innovators, meaning that they introduced a radically new product that involves patent protection, have higher profits.[vii] Finally, while some inventions are not patented, patents are obtained for almost all economically and historically significant inventions.[viii]

Patent data, like most data sets, has limitations. While patents measure the flow of new ideas, for three important reasons they measure innovation only partially: patents do not include non-patented innovations (e.g., trade secrets); not all patents result in commercialization; and many patents are strategic in nature.[ix] Trade secrets are important when discussing space technologies as some of these will be launched into space and the possibility of being reverse-engineered or stolen is less of a concern than in other sectors. Therefore, space-related inventions are more likely to be missed in patent counts than inventions in other innovation sectors.

Below are the primary ways to view or interpret patent data:

Market Reach: **When an organization decides to patent in a market, it is signalling that the market is important for them. Therefore, an aggregate count of worldwide patents by an organization shows where it intends to manufacture and sell its innovation-based products. However, it does double and triple count inventions and is therefore not a measure of innovative activity per se.**

Innovative Activity: **In order to better measure innovative activity we must count each patented invention only once, regardless of how many jurisdictions it has been patented in. Fortunately, international patent data sets allow for the formation of patent families whereby each family includes all patents related to a single invention.**

Relative Advantage: **When comparing countries of different sizes it is important that we consider relative patenting performance, since it is unlikely that industries or innovators from smaller countries would have an absolute advantage in a particular technology area. The Organization for Economic Cooperation and Development (OECD) and the World Intellectual Property Office (WIPO) have both developed metrics that adjust for country size.**

DEVELOPMENT OF THE PATENT SEARCH STRATEGY

The identification of patents in a particular technology area or industry can be challenging as patents are classified based on the science contained in them. This is done to ensure that the appropriate patent examiner receives the patent application. The science in a given patent can be used in many technology areas or industries. For this reason the development of a strong patent search strategy is essential to appropriately identify the patents in a specific technology area or industry.

The majority of the analysis in this report is based on the Derwent Innovation's Patent Family data and using the Derwent World Patents Index. These families are defined as drawing together patents covering the same invention across countries and their relationship is defined by the priority or application details claimed by each document. A patent family can be tagged to multiple classifications. Thus, it is important to note that patented inventions may appear in multiple sub-sectors of the space industry.

The following section describes, at a high level, the step-by-step and sometimes iterative process that CIPO and the CSA undertook to arrive at a search strategy that would result in a data set that best reflects patenting in the space sector. The objective was twofold: first, the extraction of patent data to better understand patenting in Canada's space industry; and second, to create a benchmark for comparison with other space-faring nations.

The task of creating a search strategy for identifying space-related patents involves identifying specific terminology and patent classification codes. The first step was to examine existing methodologies, best practises and lessons learned. The *2012 OECD Handbook on Measuring the Space Economy* was used as a foundation for the search strategy. The International Patent Classification (IPC) system for technologies was used to classify patent documents as it provides a uniform approach. This allows for the information to be compiled at the international level, with the ability for it to be further refined nationally for some high-level benchmarking, seen in the *Patenting In The Space Sector* section of this report.

The next step was to engage patent examiners that work in technology areas where space patents are most common. A CIPO classification examiner was brought in to help produce and refine a list of IPC codes and keywords associated with the space industry. In order to further strengthen the search strategy and to reduce the number of inventions unrelated to space technologies, CSA engineers and CIPO patent examiners matched a more precise list of industry keywords to the IPC codes that had been identified.

Ultimately, the list of IPC codes and keywords were selected based on their relevance and in accordance with the four leading technologies of the Canadian space sector: space robotics, optics, satellite communication and space-based radar. The final search strategy, which covered the period of 1996 to 2015, included 58 IPC codes and over 185 keywords, resulting in a final output of more than 86,000 patented inventions worldwide. This data set was used for the international trend analysis and benchmarking.

Of the 86,000 patented inventions worldwide, more than 1,200 involved a Canadian firm, government, academia, or research institution. For clarity, we will be referring to the grouping of firms and research institutions as organizations for the remainder of this report. These 1,200 patented inventions belong to more than 200 Canadian organizations. It should be noted here that while research institutions were included in the analysis, universities were excluded, as it was decided that this report would focus on industry. Using data from the CSA's annual survey of the space sector, the identities of organizations operating in the Canadian space sector were confirmed. These included organizations with 100% revenues in the space industry or organizations with activity identified as being space industry related. Specifically, a set of criteria was used to identify organizations involved in the space industry, and those with no involvement were removed. Those organizations that were removed had the following criteria: the organization was unable to be categorized according to stream, sector, and value-chain; the organization did not operate in the space sector despite initial indications in the patent data; or the organization was no longer active and there was no way to confirm the type of operations associated with the organization.

This filter resulted in a sub-set of 128 organizations operating and patenting in the Canadian space sector. Hereafter, it is referred to as the CSA-CIPO data set. While this does not represent the entire Canadian space sector, it is a very good representation as the ten largest organizations account for almost 90% of the revenue and over 70% of the employment of the sector.[x] Of the ten largest organizations, eight were identified as actively patenting and were captured within the CSA-CIPO data set. The resulting patent data set is used for the in-depth analysis of the Canadian space sector. To summarize, Figure 1 shows a breakdown of patented inventions by data set.[1]

Figure 1: Breakdown of Patented Inventions by Data Set, 1996-2015

[1] If interested, please contact CIPO at CIPO-IPResearch@canada.ca for a copy of the search strategy.

THE SPACE INDUSTRY: ECONOMICS AND INNOVATION

Historical data on the space sector is limited, and only became widely available to the public starting in 2005. Figure 2 benchmarks the growth, in real terms, of the global and Canadian space sectors. In 2005, global space revenues were over $185 billion (USD) and grew to more than $323 billion (USD) by 2015.[xi] The Canadian story shows more modest growth, from $2.5 billion (CAD) to $3.6 billion (CAD) over the same period.[xii]

Canadian and Global Space Sector Revenues
Growth Index, 2005=100

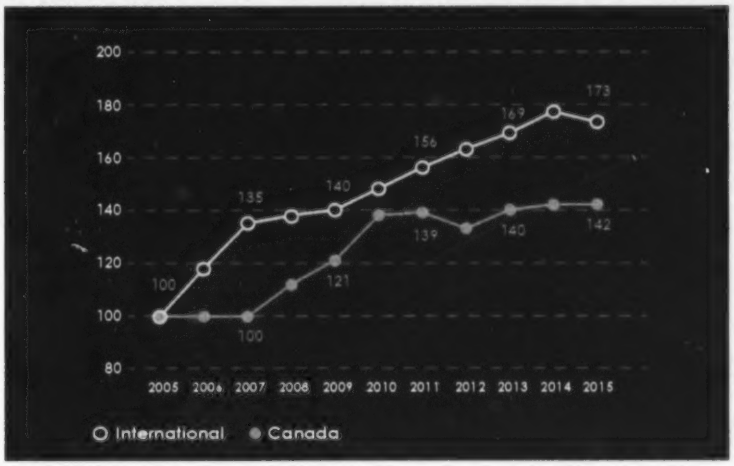

Figure 2: Benchmarking growth in the global space sector and the Canadian space sector

The CSA has been conducting an annual survey of the space sector in Canada since 1996, and publishes an annual report called the *State of the Canadian Space Sector*. This report provides comprehensive information on the economic activity generated in the Canadian space sector measured primarily through revenues, exports and employment, highlights the impact of space investments on the economy, and it is used to compare, analyze and help interpret the patented inventions data set generated for this report.

The 2015 CSA survey shows that business expenditures on R&D was higher than ever with investments of $256M (CDN) in R&D. In fact, space manufacturing R&D-intensity is more than nine times higher than the national manufacturing average in Canada.[xiii] Specifically, R&D-intensity in the space manufacturing sector for 2015 was 32%, compared to the manufacturing average R&D-intensity of 3.5% in Canada.[xiv] This is not surprising given that the complex nature of the space sector demands the most cutting-edge technology.

Of the 128 organizations found to have patented inventions in the space sector, the CSA had detailed information on a total of 48. The 48 organizations were organized according to revenues, employees, R&D expenditures, and number of patent filings. Bivariate regressions of the 48 organizations found statistically significant positive correlations between the number of R&D employees per organization and annual patented inventions; revenues and R&D expenditures; revenues and R&D employees; R&D expenditures and R&D employees; and R&D expenditures and the number of annual patented inventions by the organization (results can be seen in Appendix A).

The relationship between R&D expenditures and R&D employees suggests that Canadian space organizations spend a majority of R&D related costs on researchers, scientists, and engineers, rather than testing facilities or laboratories. This has implications for the space sector and requires further investigation.

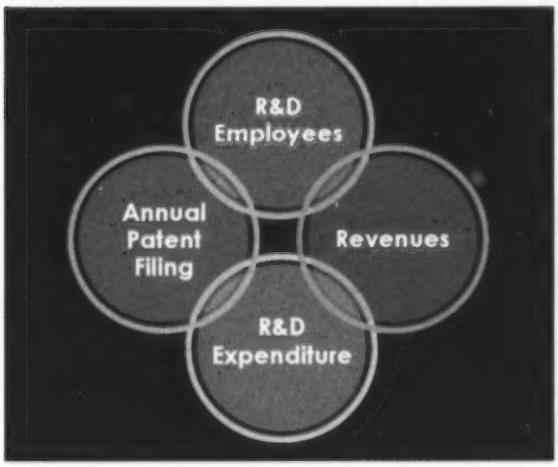

Figure 3: Relationship between revenue, employees, R&D expenditures and the number of patent filings

The positive relationship between R&D expenditures and patent filing is consistent with the literature. However, there is no conclusive evidence for the effect of patent filing on the revenue of an organization. A richer data set would be required to fully understand this relationship and the role patents play in increasing an organization's competitive advantage in the space sector.

The similarities between the Canadian space sector and the CSA-CIPO data set suggest that the sample is highly representative of the overall space industry in Canada; this was confirmed internally through a review of the associated organizations. This confirmation is further explained by the fact that the space sector in Canada is relatively small and led by a few dominant organizations. In Canada, the top 30 organizations in the space sector account for 98% of the revenues. The CSA-CIPO data set identified 85% of the top 30 organizations (excluding universities).[xv] It is significant that the majority of those organizations are actively patenting and were captured within the CSA-CIPO data set.

Further analysis of the data describes the areas of patent activity that are most active. In a breakdown of the number of organizations (48) within the subset, 52% were small organizations (1-99 employees); 31% were medium-sized organizations 100-499 employees); and the remaining 17% were large organizations (500+ employees). The categorizations used the groupings identified in CSA's Canadian Space Sector survey which are based on Statistics Canada's definition of small, medium and large organizations. While only 17% were large organizations, they accounted for 70%

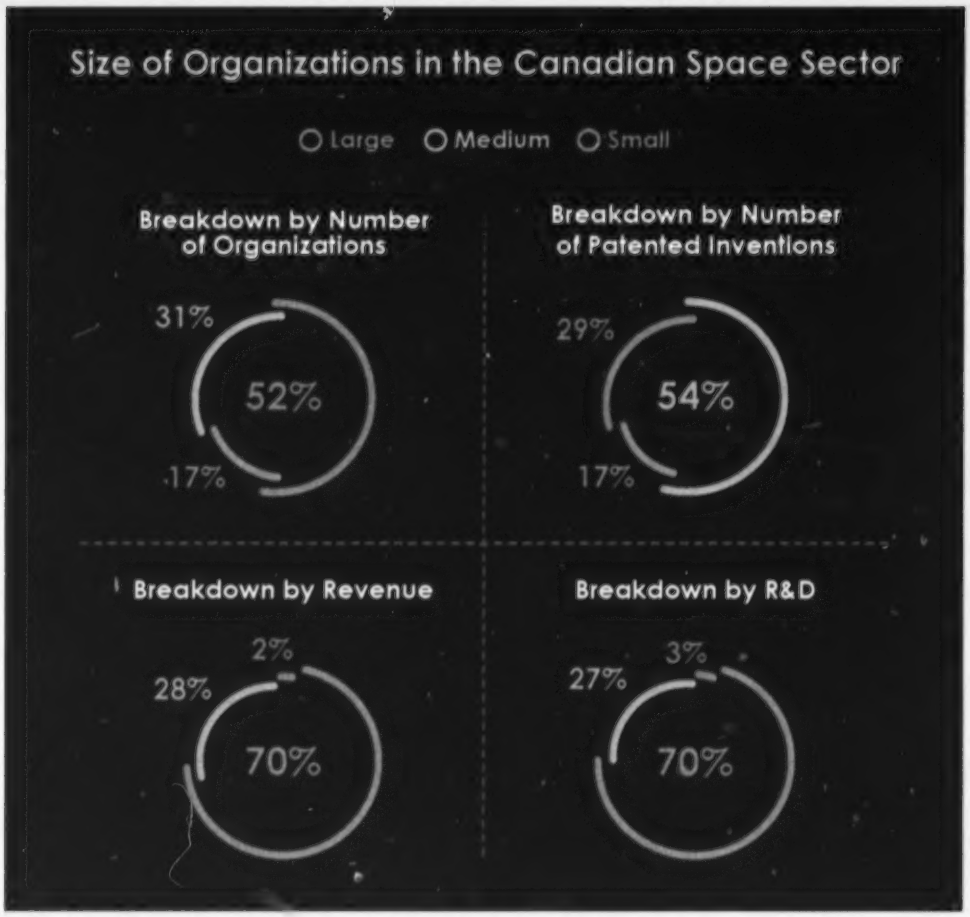

Figure 4: Size of Organizations in the Canadian Space Sector

of the revenue and R&D in the sector. On the other hand, while small organizations accounted for only 1.8% of revenue, they are 1.7 times more R&D-intensive than the larger organizations, accounting for 3.1% of R&D. Moreover, they accounted for 29% of the patented inventions. It seems that the space sector is characterized by a handful of very large players and a larger number of small innovative organizations. More research is required to better understand this dynamic. However, surveys have shown that small organizations that hold patents are more likely to be exporters and high-growth organizations, which bodes well for the space sector in Canada given the number of small organizations patenting.[xvi]

PATENTING IN THE SPACE SECTOR

The International Perspective

Space patent activity may be much more prolific than previously thought. The data from our search strategy indicates that, if the sector is defined broadly, there were about 7,000 patented inventions in 2013 (Figure 5). By comparison, an OECD study indicated that patenting in the space sector peaked in 2000 with about 1,500 patented inventions worldwide.[xvii] In contrast, a United Kingdom Intellectual Property Office (UKIPO) study showed that in 2010 there were almost 2,500 patented inventions in satellite technologies alone.[xviii] The differences are due to variances in the methodologies. This report used a more extensive search of IPC codes and descriptor keywords than traditional patent analytic reports. The large size as well as the large number of organizations in the data set meant that it was not possible to assess the level of participation of each entity in the space sector as we did for Canada. That being said, the data set is robust and is appropriate for trend and comparative analysis.

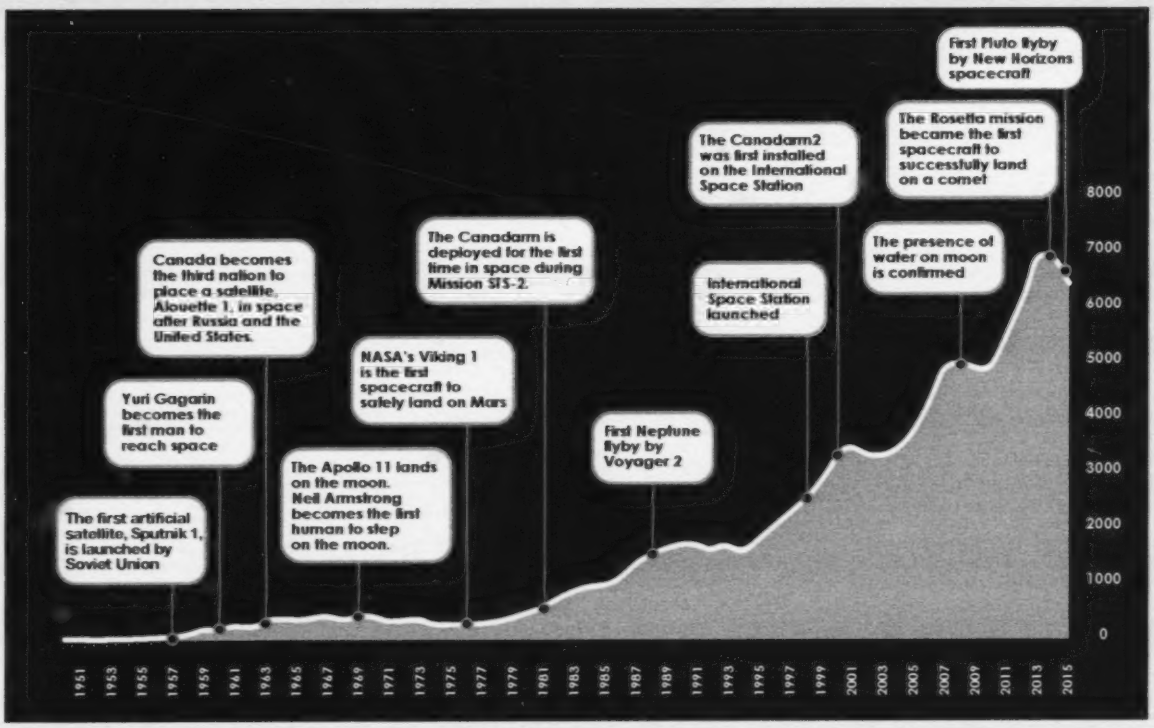

Figure 5: Patented Inventions Over Time and Major International Events in the Space Sector

In the early stages of the 1950s, patented space inventions were relatively flat. It wasn't until the mid- to late 1950s that the patenting of space-related inventions started to increase. This coincides with the time of the first artificial satellite launched by the Soviet Union, Sputnik 1. Filings in the global space sector gradually increased until the late 1960's. Interestingly, once Apollo 11 landed on the moon and Neil Armstrong walked on it, filings actually decreased until the mid- to late 1970s. From the late 1970s onwards, patent filing in the space sector has grown consistently as patented inventions are now more than 20 times greater in number than in 1978.

Based on the main IPC codes associated with patented inventions in the space sector (Figure 6), we see that each technology evolves in its own way over time. Interestingly, inventions coded to IPCs associated with vehicles or equipment that are specifically adapted for cosmonautics (B64G) experienced a wave of growth around the turn of the century and then retreated in the early to mid-2000s before regaining momentum from 2010 to 2014. On the other hand, patented inventions in Radio Direction-Finding (G01S), which represent the largest share of inventions, experienced consistent growth over the 1996-2015 timespan.

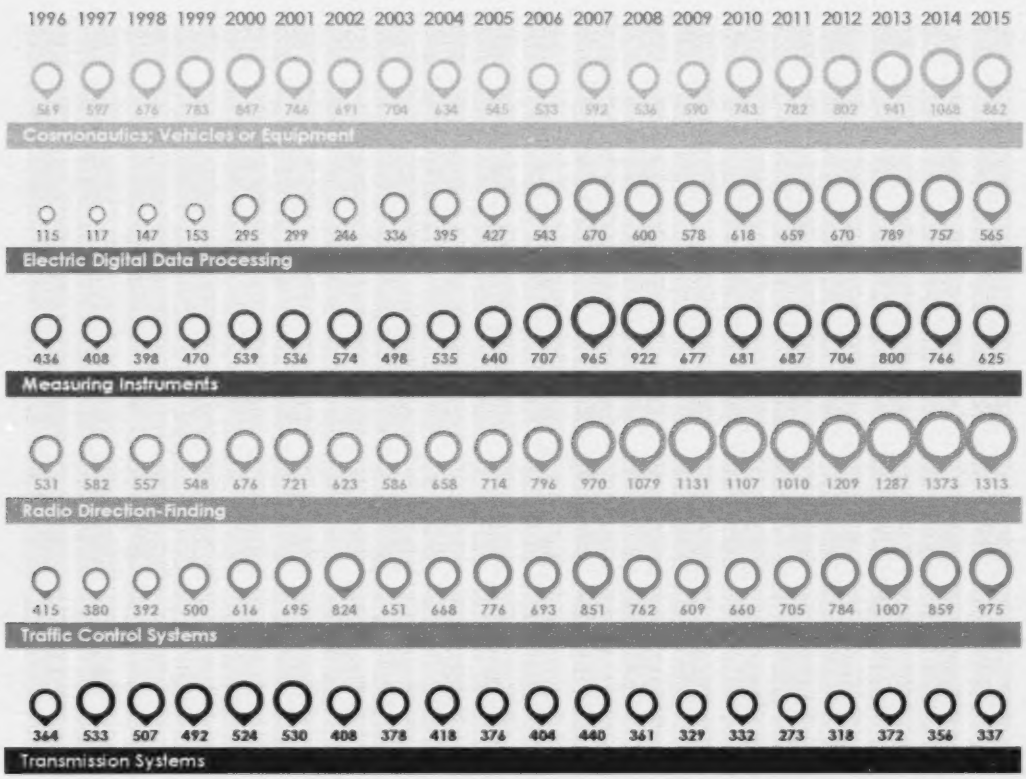

Figure 6: Evolution of Innovation by Technology

The other technologies included in the chart (electrical digital processing, measuring instruments, traffic control systems and transmission systems) are also coded to many space-related inventions, and each appears to evolve differently over time, perhaps corresponding to a shift in the technology needs of the space sector.

Patent activity is an important indicator of innovation within an industry, and can further explain the directions and types of technologies being created. Below is an example of a patent landscape map (Figure 7). The map is generated by an algorithm that uses keywords from patent documentation to cluster patented inventions according to shared language. The patented inventions are organized based on common themes and are grouped as 'contours' on the map to identify areas of high and low patent activity. The lightly coloured purple peaks represent the highest concentrations of patented inventions, and each peak is labelled with key terms that tie the common themes together. The distance between keywords helps to illustrate the relationship to one another where shorter distances between peaks indicate that the patented inventions they represent share more commonalities relative to those that are further apart. Words located close together may be part of similar systems or technologies, whereas keywords that are further apart likely have less of a relationship.

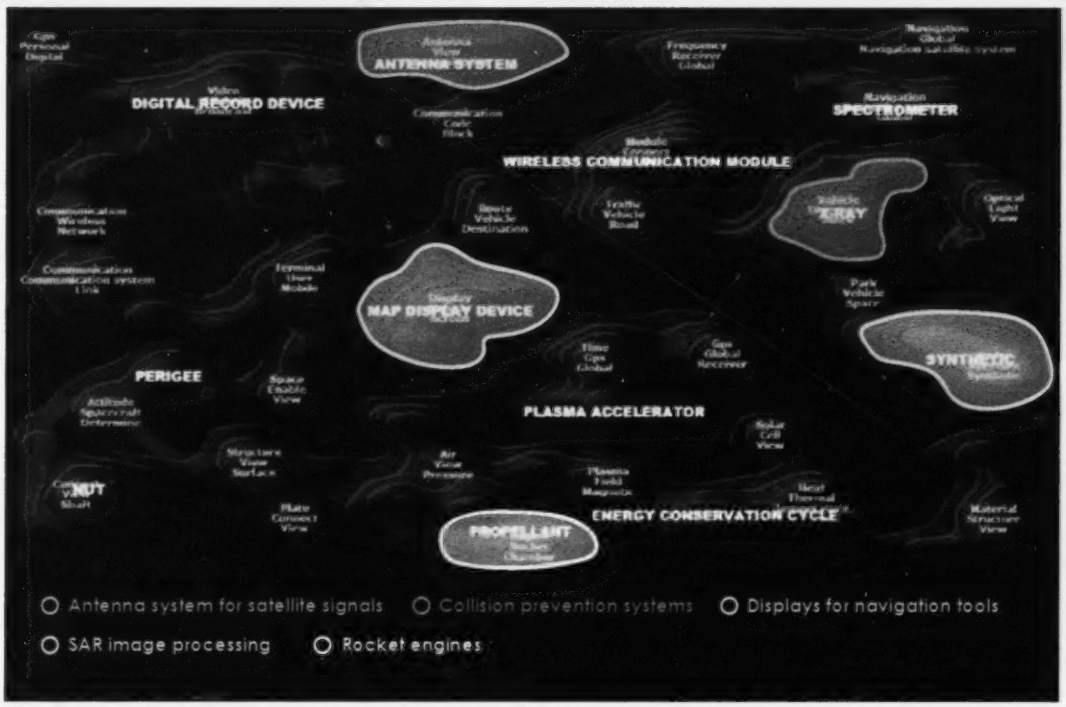

Figure 7: International Level Patent Landscape Map (84k patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure7.

As noted previously, the use of the keywords presented in the map, along with the most common IPCs found in the patents, allows for the identification of various technological areas with patent activity in the sector. Note that many keywords are ubiquitous and would be found in other industries and technologies. For this reason the space specific keywords found in the landscape map are more useful. More widely-used keywords could then be applied to further refine the patent search. The opaque or less-visible keywords would provide a second level of detail. The intention is to facilitate exploration of the patent data by those interested in the technology or industry.

Figure 7 above shows that the highest concentration of patented inventions in this international data set relates to patented inventions comprising keywords such as "Video, Digital, Broadcast," "Antenna, View, Communication," "Display, Vehicle, Screen," "Engine, Rocket, Chamber," "Module, Connect, GPS," "Traffic, Vehicle, Road," "Vehicle, Determine, Block," "Navigation, Navigation System, Global," "Radar, Aperture, Synthetic," and "Optical, Light, Blue." The dark blue space separating the purple coloured topography highlights technological areas of patent activity that are very different from each other. The top IPC codes in this international data set are: G01S (Radio Direction Finding), B64G (Cosmonautics), G08G (Traffic Control Systems), G01C (Measuring Distances, Levels or Bearings), and G06F (Electrical Digital Data Processing).

Diving deeper into the patent data, peaks in the international level landscape map can be linked to more specific technologies that are identified in the legend below the map and that correspond to the coloured areas on the landscape map. The peak highlighted in green and corresponding to the prominent keyword "SYNTHETIC," can be linked to patented inventions related to Synthetic Aperture Radar (SAR) image processing. The peak highlighted in orange and corresponding to the prominent keyword "ANTENNA SYSTEM," can be linked to patented inventions in the field of research of antenna systems for satellite signals. The peak highlighted in blue and corresponding to the prominent phrase "MAP DISPLAY DEVICE," can be linked patented inventions related to displays for navigation tools. The peak highlighted in yellow and corresponding to the prominent keyword "PROPELLANT," can be linked to patented inventions related to rocket engines. Finally, the peak highlighted in red and corresponding to the prominent keyword "X-RAY," can be linked to patented inventions related to collision prevention systems.

To gain a better understanding of Canada's patenting performance in the space sector, we use the Revealed Technological Advantage (RTA) index, which was developed by the OECD (additional detail in Appendix B). This measure uses patenting intensity to allow for industries to be compared between countries of different sizes on a relative basis. The RTA index provides a ratio of each country's share of patented inventions within the space technology sector as a share of the country's total patented inventions produced within a given timeframe. Canada has a value greater than one, suggesting a technological advantage for our space sector. Therefore, with regard to the space sector, Canada has more influence internationally than its size would suggest. The result presented below is corroborated by previous results from the OECD in their *Space Economy at a Glance 2014* report.

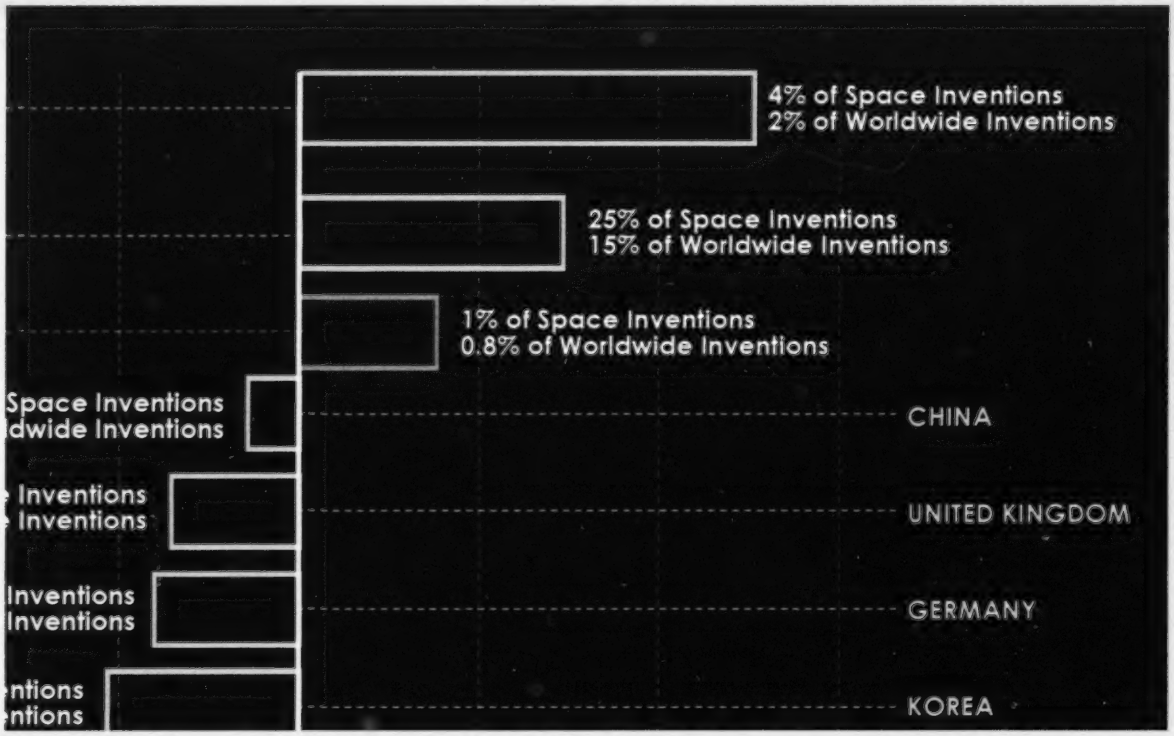

Figure 8: Revealed Technological Advantage Index, 1996-2015

The Canadian Perspective

The previous section showed that internationally, space-related patented inventions have enjoyed strong growth over the past 40 years. In addition, results from RTA assessments confirm that Canada has strengths in the space sector. It is therefore no surprise that Canada has also experienced strong growth, more than doubling the number of patented inventions in the last 10 years, rising from 40 to 87. Figure 9 presents an overview of the evolution of Canadian space-related patented inventions and key events between 2005 and 2015.

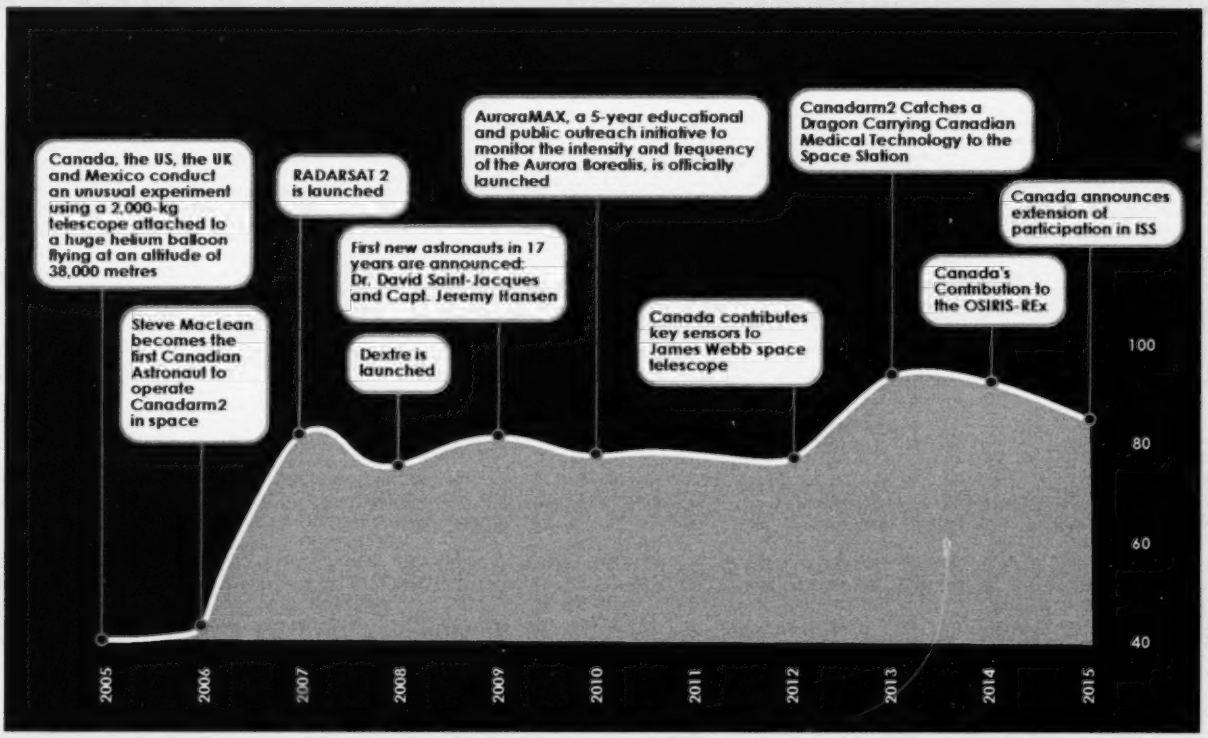
Canada, the US, the UK and Mexico conduct an unusual experiment using a 2,000-kg telescope attached to a huge helium balloon flying at an altitude of 38,000 metres
Steve MacLean becomes the first Canadian Astronaut to operate Canadarm2 in space
RADARSAT 2 is launched
First new astronauts in 17 years are announced: Dr. David Saint-Jacques and Capt. Jeremy Hansen
Dextre is launched
AuroraMAX, a 5-year educational and public outreach initiative to monitor the intensity and frequency of the Aurora Borealis, is officially launched
Canada contributes key sensors to James Webb space telescope
Canadarm2 Catches a Dragon Carrying Canadian Medical Technology to the Space Station
Canada's Contribution to the OSIRIS-REx
Canada announces extension of participation in ISS
100
80
60
40
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

Figure 9: Patented Inventions Over Time by 128 Canadian Firms and Major Canadian Events in the Space Sector

Looking at the growth observed in Figure 9, it begs the question of whether this growth is led by a small concentration of organizations or whether the growth is a result of increased patenting in the sector by multiple organizations. Figure 10 presents the concentration of patenting by Canadian organizations in the Canadian space sector. The bar chart on the left displays the patenting profile of Canadian organizations in the Canadian space sector, while the doughnut chart on the right displays the share of total Canadian patented inventions in the space sector from 1996-2015 for each group. It can be seen that there is no one dominant group that drives the patenting in this sector. While there are six organizations that have more than 20 patented inventions in this period, they account for just over a third of patenting in the Canadian Space Sector over this time. Further, when the analysis is looked at on a yearly basis, there is no one organization that dominates patenting in any given year. It can be concluded that patenting in this sector is dispersed over a number of organizations and growth is not a consequence of a few organizations patenting but rather the sector as a whole.

The Canadian space sector technologies associated with patented inventions can be partially illuminated through an analysis of the keywords included in the patent titles and abstracts. The patent landscape map in Figure 10 associated with the 128 Canadian organizations shows that the highest concentration of patented inventions relate to patents comprising keywords such as "Spacecraft, Refuel, Oxidizer," "Flow, Injector, Chamber," "Joint, Robotic, Rotate," "Layer, Material, Surface," "Message, AIS, Identification System," "Electrode, Wave electrode, Mach-zender,"

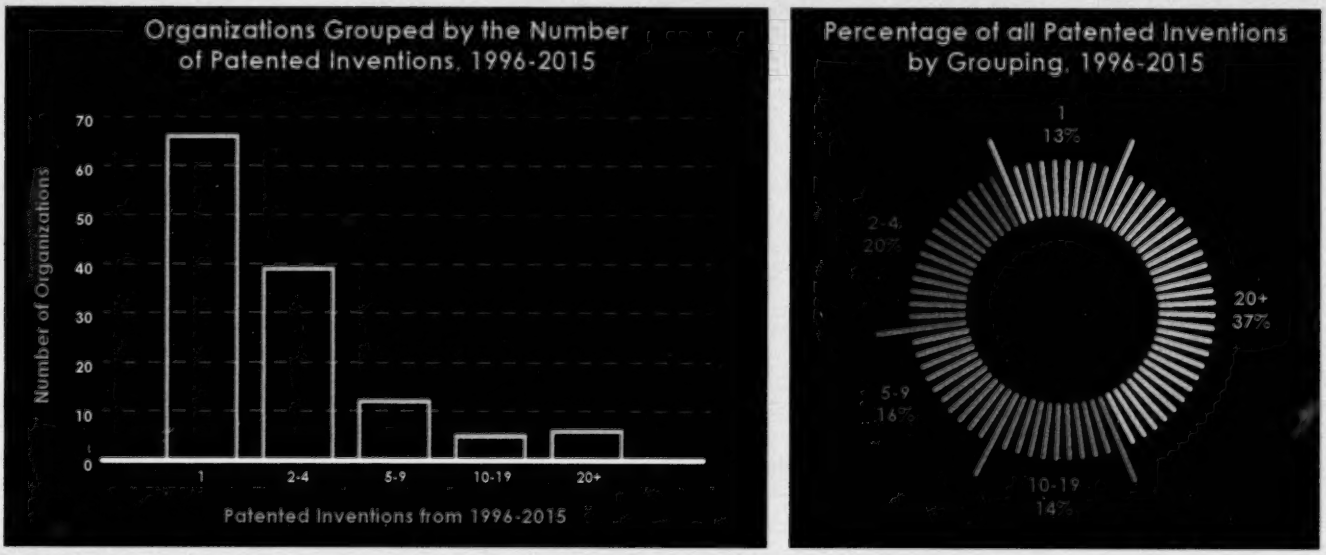

Figure 10: Concentration of Patenting by Canadian Organizations, 1996-2015

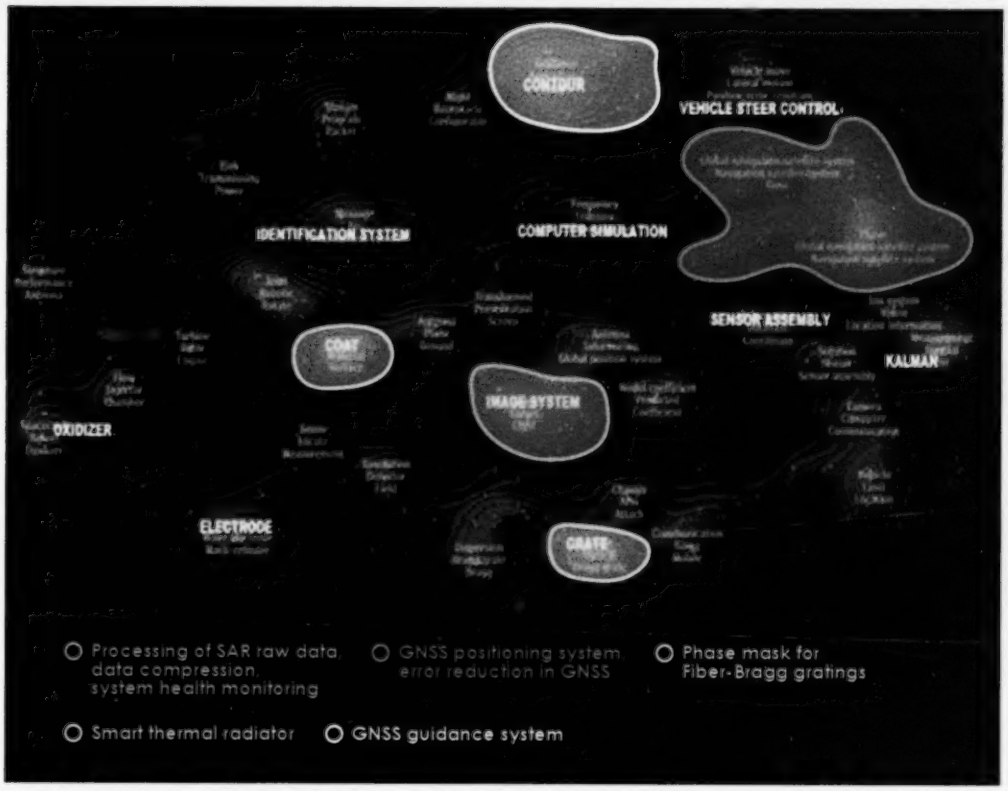

Figure 11: Landscape Map of Patented Inventions by 128 CSA Canadian Companies (493 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure11.

"Dispersion, Bragg grate, Bragg," "Grate, Optical, Bragg grate," "Image, Target, Light," "Guidance, Agricultural, Guide," "Antenna, Information, Global Positioning System," "Model coefficient, Predicted, Coefficient," "Phase, Global navigation satellite system," "Vehicle, Limit, Location," and "Measurement, Inertial, INS." The top five IPC codes in this data set are G01S (Radio Direction Finding), G01C (Measuring Distances, Levels or Bearings), H04B (Transmission), G02B (Optical Elements, Systems, or Apparatus), and G06F (Electrical Digital Data Processing).

As noted previously, the use of the keywords presented in the map along with the most common IPCs found in the patents facilitate the identification of various technological areas under development in the sector. Note that many keywords are ubiquitous and would be found in other industries and technologies. For this reason, the space-specific keywords found in the landscape map are more useful. More widely-used keywords could then be used to further refine the patent search. The opaque or less-visible keywords would provide a finer level of detail. The intention is to facilitate exploration of the patent data by those interested in the technology or industry.

Figure 12: Canadian space clusters Identified in the data by number of organizations

Taking this landscape map and analyzing the patent data a little further, some key technologies become apparent. Listed in the legend below the map, and corresponding to the peaks that are highlighted in colour, the key technologies associated with each peak can be found. The peak highlighted in green and corresponding to the prominent keyword "COAT," can be linked to patented inventions related to smart thermal radiators. The peak highlighted in orange and corresponding to the prominent keyword "IMAGE SYSTEM," can be linked to patented inventions in the field of research of processing SAR raw data, data compression, and system health monitoring. The peak highlighted in blue and corresponding to the prominent keyword "GRATE," can be linked to patented inventions related to Phase masks for Fiber-Bragg gratings. The peak highlighted in yellow and corresponding to the prominent keyword "CONTOUR," can be linked to patented inventions related to Global Navigation Satellite System (GNSS) guidance systems. Finally, the peak highlighted in red can be linked to patented inventions related to GNSS positioning systems and error reduction in GNSS.

The high-level keyword analysis takes the most popular terms into consideration, irrespective of the underlying sectors and value-chain segments. This indicates that the keywords identified in the national analysis represent the overall trends, but do not highlight trends within subsections of the Canadian space sector. Therefore, as the landscape analysis progresses through sector and value-chain categorizations, the keywords and trends will change.

Cluster Analysis

Putting a lens on the 128 Canadian organizations found in the CIPO-CSA data set and their geographic location, five large clusters associated with the Canadian space sector can be identified. The largest cluster of organizations is formed in the vicinity of Canada's most populous region, the Greater Toronto Area, and includes 35 organizations. The second largest cluster, with 24 organizations, was grouped in the vicinity of the city of Montreal, Canada's second most populous city. The three other clusters are centered around Vancouver (16 organizations), Calgary (14 organizations) and Ottawa (14 organizations). There are many benefits for organizations in the same industry to cluster together, including increased productivity, faster innovation through collaborative research, and the creation of small organizations to cater to the niche needs of this industry.[xix]

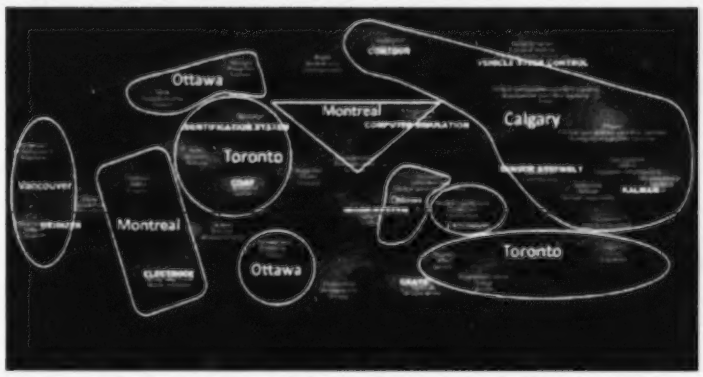

Figure 13: Landscape Map of Patented Inventions by 128 CSA Canadian Companies with Geographic Cluster Overlaid (493 patented inventions)
This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure13.

With a lens on the Canadian cluster of organizations mentioned above, it is interesting to overlay geographic location on top of a patent landscape map to identify specific technologies with clusters. This can be seen in Figure 13.

Innovation and Collaboration in the Space Value Chain

Global value chains are becoming increasingly important in most industries, and the space sector is no different. Value chains have both upstream and downstream components. The upstream segment refers to the effort required to design, test, build, integrate and launch assets into space. The downstream segment refers to the effort required for the day-to-day operation of space assets, manufacturing of products and software applications that transform space data and signals into useful end products, and services provided to end users. Six segments have been identified for the Canadian space sector: three that are upstream and three that are downstream. Specifically, these are:

Upstream

1. Research, Engineering and Consulting — R&D related to non-commercial/pre-commercial activity; design and engineering support for space systems; support services which enable other space sector actors to exist.
2. Ground System Manufacturing - Building and integration of facilities and equipment on Earth for satellite operations.
3. Space System Manufacturing - Building and integration of spacecraft, satellites, payloads or any component thereof.

Downstream

1. Value-Added Products and Applications — Manufacturing or development software or hardware that enable the transformation of space-derived resources into a useful format, i.e. computer software applications, antennas, satellite phones, video and audio receivers/decoders, GPS devices.
2. Satellite Operations — Day-to-day management of satellites and spacecraft once they are in space, e.g. telemetry, tracking and command; monitoring, recovery operations and collision avoidance; mission planning; uplinks and downlinks to reception facility; lease or sale of satellite capacity.
3. Services — Provision of services which are dependent on space-based signals or data to various end-users, such as subscribers to satellite radio, phone, TV or Internet services; engineering, architectural and environmental consulting services based on the processing and analysis of space data.

A combination of publicly-available information and survey data allowed for the categorization of Canadian organizations into the six segments of the value-chain. This permitted us to observe upstream/downstream and value-chain patent activity involving collaboration within the space sector.

Figure 14 is an effective way to visualize organizations that are collaborating. The example clearly illustrates the breadth and reach of space-related technologies to both traditional and less conventional organizations within the space sector. For example, the CSA has worked with Thomson-CSF Optronics, The Centre for Research in Earth and Space, and Allied Signal Inc. Many of the organizations identified as having patented inventions have since amalgamated or been acquired. An example is Allied Signal, which was purchased by Honeywell in 1999; or COGO Optronics, which was acquired by Teraxion in 2013. Other organizations have a more tertiary connection to the space sector, but nonetheless played a pivotal role in developing space-related services and technologies. Both acquired and tertiary organizations are highlighted in dark grey.

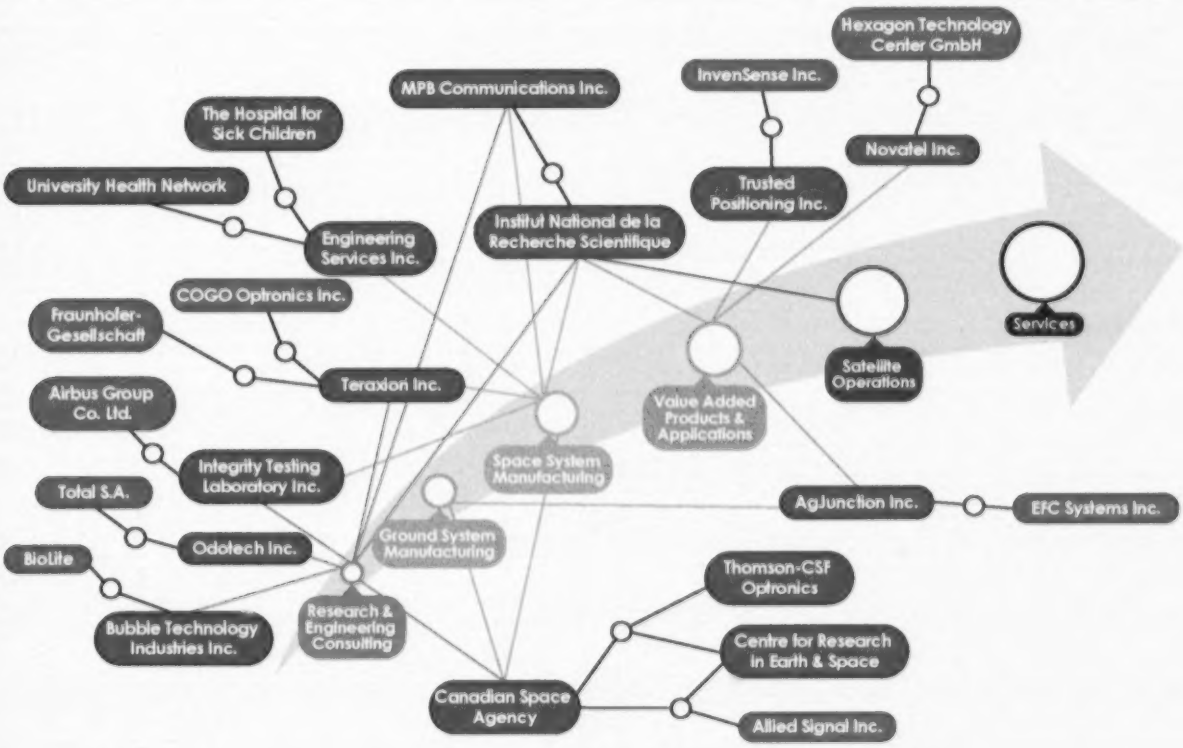

Figure 14: Canada collaboration map of each of the six 'links' in the value chain

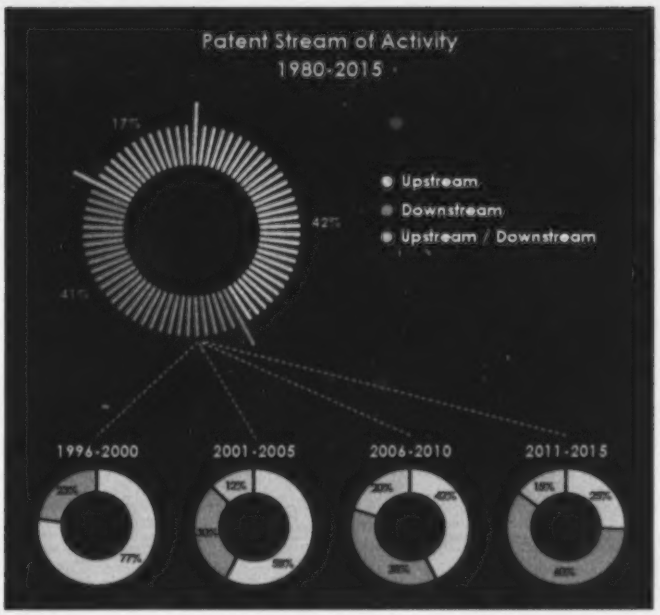

Figure 15: Share of patent activity in the upstream and downstream segments, 1980-2015

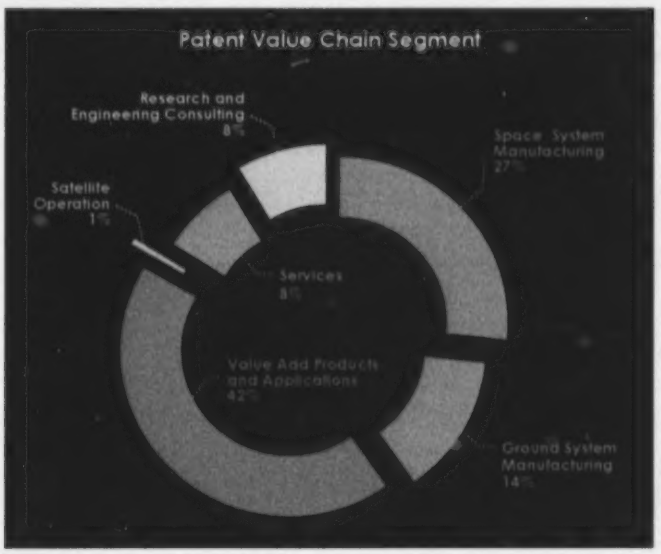
Patent Value Chain Segment
Research and Engineering Consulting 8%
Space System Manufacturing 27%
Satellite Operation 1%
Services 8%
Value Add Products and Applications 42%
Ground System Manufacturing 14%

Figure 16: Patent value chain sector

Figure 15 presents the share of patent activity in the upstream and downstream segments, as well as where the activity overlaps. It also demonstrates the trend over the last 20 years.

The trend towards downstream activity is not surprising. It follows the Canadian and international shift towards more private sector space activity and revenues as the cost to access space falls and smaller off-the-shelf technologies are used such as small satellite constellations.

When examining the six individual segments in more detail, Figure 16 shows Value Added Products and Applications accounting for the highest proportion of patented inventions (42%). From the earliest stages of the upstream position to the latest, Research & Engineering, and Consulting accounts for 8% of patented inventions, Ground System Manufacturing accounts for 14%, while Space Systems Manufacturing accounts for 27%. The Services segment accounts for only 8% of patented inventions; this is not unexpected given that this segment primarily relates to business operations rather than the inventive process. Of particular interest is that there are almost no patented inventions in the Satellite Operations segment, which may reflect changing methodologies and classifications of organizational activity within CSA's annual survey on the Canadian space sector. These results support the trend towards increased patenting in the downstream segment of the space industry.[xx]

Patent Landscape Maps

To better understand patenting within each segment, the patent-related data can be presented as a landscape map for each segment. As noted previously, the use of the keywords presented on the map, along with the most common IPCs found in the patents, allows for the identification of various technological areas under development in the sector. Note that many keywords are ubiquitous and would be found in other industries and technologies. For this reason the space-specific keywords found in the landscape map are more useful. More widely used keywords could then be used to further refine the patent search. The opaque or less-visible keywords would provide a finer level of detail. The intention is to facilitate exploration of the patent data by those interested in the technology or industry.

In the Research & Engineering Consulting segment, 34 patented inventions were identified, with the prominent keywords being: "SAMPLE", "BOX", "SUPPLY", "COAT" and "TARGET AREA". These keywords are not particularly space-specific, and neither are the second-level keywords. The use of these keywords with the appropriate IPC codes would facilitate the identification of patented inventions in space related technologies for this value-chain segment. Top IPC codes in the Research & Engineering Consulting segment include: G01S (Radio Direction Finding), H02J (Circuit Systems for Electrical Power), B64G (Cosmonautics), G01J (Measurement), and G01N (Investigation of Materials).

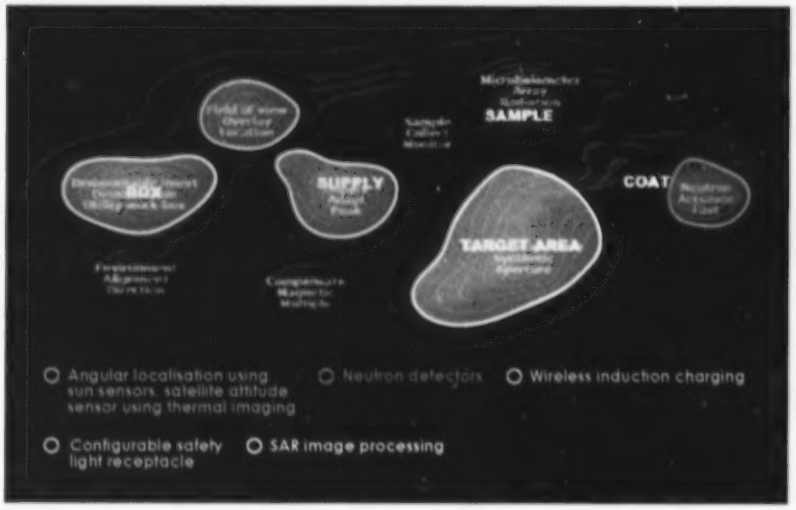

Figure 17: Canadian patented inventions in Research & Engineering Consulting (34 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure17.

Diving deeper into the patent data, peaks in the Research and Engineering Consulting landscape map can be linked to more specific technologies that are identified in the legend below the map and that correspond to the coloured areas on the landscape map. The peak highlighted in green and corresponding to the prominent keyword "BOX," can be linked to patented inventions related to configurable safety light receptacle technologies. The peak highlighted in orange and corresponding to the second-level keywords "Field of view, Overlay, and Location," can be linked to patented inventions in the field of research of angular localisation using sun sensors, and satellite attitude sensor using thermal imaging. The peak highlighted in blue and corresponding to the prominent keyword "SUPPLY," can be linked patented inventions

related to wireless induction charging. The peak highlighted in yellow and corresponding to the prominent keyword "TARGET AREA," can be linked to patented inventions related to SAR image processing. Finally, the peak highlighted in red and corresponding to the second-level keywords "Neutron, Accurate, and Fast," can be linked to patented inventions related to neutron detectors.

In the Ground Systems Manufacturing value chain segment, 42 patented inventions were identified, with the prominent keywords being: "TRANSMITTED", "DIGITIZE", "CRITERION","X-RAY" and "WIRELESS DEVICE". Again these keywords are not space-specific. The use of these keywords with the appropriate IPC codes would facilitate the identification of space-related patented inventions in this value chain segment. Top IPC codes in the Ground Systems Manufacturing segment include: G08G (Traffic Control Systems), G01S (Radio Direction Finding), H04B (Transmission), G06F (Electrical Digital Data Processing), and H04L (Transmission of Digital Information).

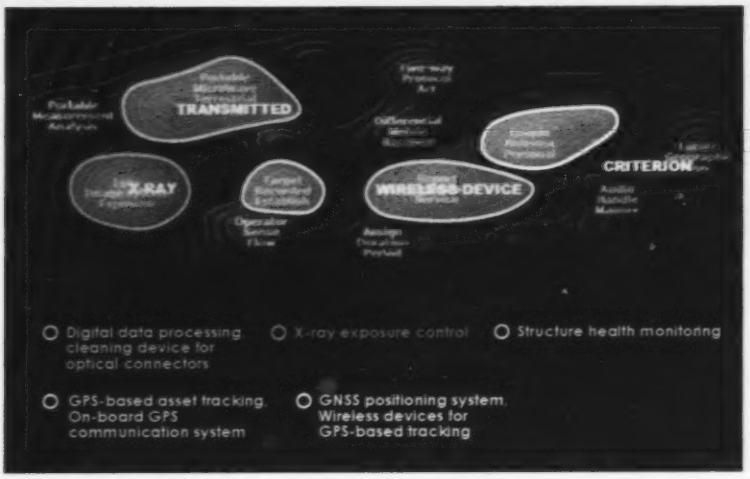

Figure 18: Canadian patented inventions in Ground System Manufacturing (42 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure18.

Taking this landscape map and analyzing the patent data a little further, some key technologies become apparent. Listed in the legend below the map, and corresponding to the peaks that are highlighted in colour, the key technologies associated with each peak can be found. The peak highlighted in green and corresponding to the prominent keyword "WIRELESS DEVICE," can be linked to patented inventions related to GPS-based asset tracking and On-board GPS communication systems. The peak highlighted in orange and corresponding to the prominent keyword "TRANSMITTED," can be linked to patented inventions in technologies linked to digital data processing and cleaning devices for optical connectors. The peak highlighted in blue and corresponding to the second-level keywords "Target, Recorded, and Establish," can be linked to patented inventions related to structure health monitoring. The peak highlighted in yellow and corresponding to the second-level keywords "Couple, Antenna, and Personal," can be linked to patented inventions related to GNSS positioning systems, and wireless devices for GPS-based tracking. Finally, the peak highlighted in red and corresponding to the prominent keyword "X-RAY," can be linked to patented inventions related to X-ray exposure control.

In the Space System Manufacturing value chain segment, 124 patented inventions were identified, with the prominent keywords being: "GARMENT", "ENGINE", "AUTOMATIC",

"ROBOTIC", "ROTOR", "OPTICAL POWER", "MODULATOR", "PHASE MASK", "CHROMATIC" and "WRITE". Many of the keywords are not particularly space-specific. However, some of the second-level keywords are more intuitive. The use of these keywords with the appropriate IPC codes would facilitate the identification of space-related patented inventions in the Space System Manufacturing segment.
The top IPC codes in the Space Systems Manufacturing segment include the following: G02B (Optical Elements, Systems, or Apparatus), H04B (Transmission), B64G (Cosmonautics), G02F (Optical Devices), and F02K (Jet-Propulsion Plants).

Diving deeper into the patent data, peaks in the Space System Manufacturing landscape map can be linked to more specific technologies that are identified in the legend below the map and that correspond to the coloured areas on the landscape map. The peak highlighted in green and corresponding to the prominent keyword "ENGINE," can be linked to patented inventions related to injectors, swirl-enhanced combustion, and all-metal wheels technologies. The peak highlighted in orange and corresponding to the prominent keyword "ROBOTIC," can be linked to patented inventions in the field of research of medical robots, reconfigurable robots, and mobile robots. The peak highlighted in blue and corresponding to the second-level keywords "Flexure joint, Gimbal, and Gimbal assembly," can be linked to patented inventions related to momentum management systems and opto-mechanical mechanisms. The peak highlighted in yellow and corresponding to the prominent keyword "OPTICAL POWER," can be linked to patented inventions related to tunable optical filters and semiconductor lasers. Finally, the peak highlighted in red and corresponding to the prominent keyword "CHROMATIC," can be linked to patented inventions related to tunable dispersion compensators.

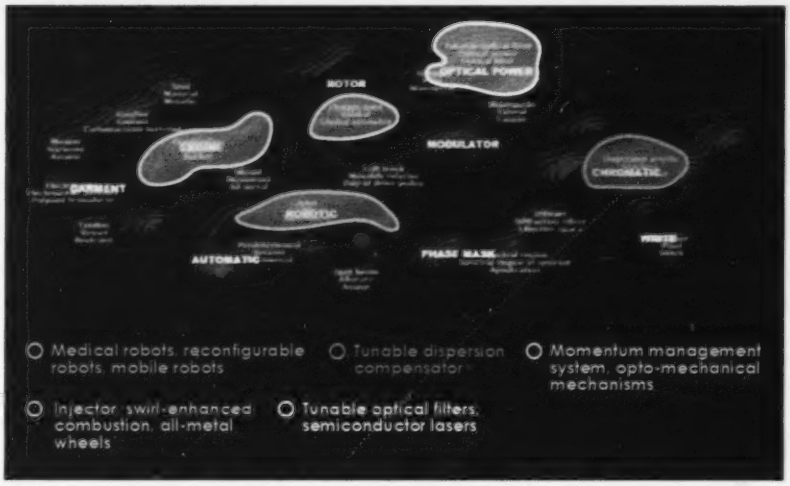

Figure 19: Canadian patented inventions in Space System Manufacturing (124 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure19.

The field of robotics has grown rapidly with recent advances in computing power, connectivity and their flexibility with being capable of performing a variety of tasks and applications. Thus, it's interesting to see a peak in the Space System Manufacturing landscape map titled "Robotic" and it begs us to dig a little deeper into the patent data. Looking at the titles and abstracts of the patented inventions located in this peak, it is possible to see a small sample of the Canadian ingenuity that is evolving in this field and how it might all relate back to the original Canadarm. Currently, Canadarm2 is being used on the ISS. Built by MacDonald, Dettwiler and Associates Ltd. in Brampton, Ontario and launched in 2001, Canadarm2 followed the original Canadarm, which was

created for space shuttle missions and was flown into space for the first time in 1981. Canadarm2's original mission was to assist in the space station's early construction and maintenance and today it is used to capture unpiloted resupply vehicles, such as SpaceX's Dragon or Orbital ATK's Cygnus. It turns out that the high precision achieved in space is also very useful for applications on Earth and the technology is a popular model for spin-offs, especially in the field of medicine.[108] The patented inventions found in this peak relate to robotics that can be used in surgery and medical imaging, as well as modular expandable and reconfigurable robotic systems and instrument packages to be used in outer space. Looking at various peaks and diving deeper into the patent data can show Canadian growth and ingenuity in niche areas.

In the Value Added Products and Applications value chain segment, 182 patented inventions were identified, with the prominent keywords being as follows: "EARTH ORBIT SATELLITE", "DIELECTRIC", "POSITION DETERMINATION", "DISCRIMINATOR", "INS SYSTEM", "TRACE", "SEED" and "TRANSFORMED PRESENTATION". A couple of these keywords are quite space-specific. In addition, a number of the second-level keywords also resonate with the space sector. The use of these keywords with the appropriate IPC codes would facilitate the identification of space-related patents in this value chain segment. Top IPC codes in the Value Added Products and Applications value chain segment include: G01S (Radio Direction Finding), G01C (Measuring Distances, Levels or Bearings), G08G (Traffic Control Systems), H04B (Transmission), and G06F (Electrical Digital Data Processing).

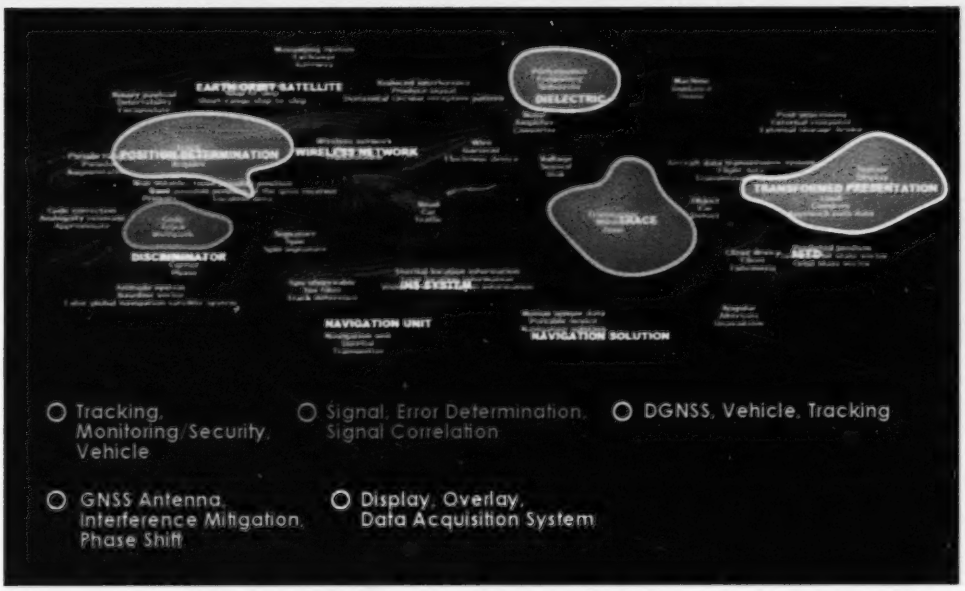

Figure 20: Canadian patented inventions in Value Added Products and Applications (182 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure20.

Taking this landscape map and analyzing the patent data a little further, some key technologies become apparent. Listed in the legend below the map, the key technologies that are associated with each colorfully highlighted peak can be found. The peak highlighted in green and corresponding to the prominent keyword "DIELECTRIC," can be linked to patented inventions related to GNSS antennas, interference mitigation, and phase shift. The peak highlighted in orange corresponding to the prominent keyword "TRACE," can be linked to patented inventions in the field of research of tracking, monitoring/security, and vehicles. The peak highlighted in blue and corresponding to the prominent phrase "POSITION DETERMINATION," can be linked to patented inventions related to DGNSS, vehicles, and tracking. The peak highlighted in yellow and corresponding to the prominent phrase "TRANSFORMED PRESENTATION," can be linked to patented inventions related to displays, overlays, and data acquisition systems. Finally, the peak highlighted in red and corresponding to the prominent keyword "DISCRIMINATOR," can be linked to patented inventions related to signals, error determination, and signal correlation.

In the Services value chain segment, 22 patented inventions were identified. The prominent keywords were: "PROVIDER", "STACK" and "COMPUTER SIMULATION". Like some of the earlier segments, these keywords are not space-specific. However, they do define some of the key inputs of a service sector in a technology-based industry (e.g., service provider, stream, etc.). The use of these keywords with the appropriate IPC codes would facilitate the identification of space-related patented inventions in this value chain segment. Top IPC codes in the Services segment include the following: H04N (Pictorial Communication), G06F (Electrical Digital Data Processing), G06T (Image Data Processing), H04L (Transmission of Digital Information), and G01V (Geophysics). The key technologies are identified in the legend below the map and correspond to the coloured areas on the landscape.

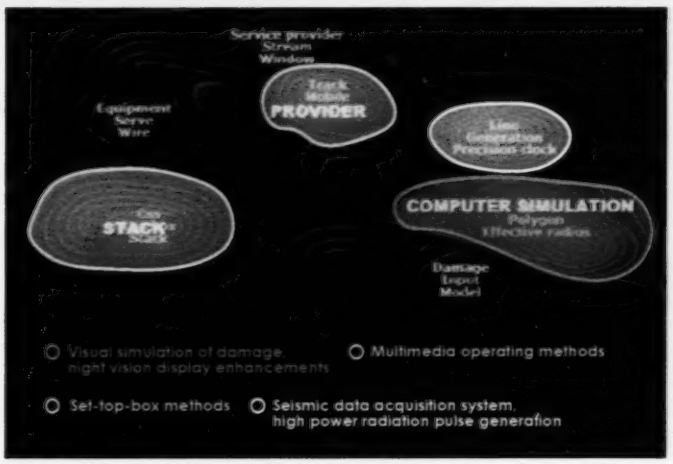

Figure 21: Canadian patented inventions in Services (22 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure21l.

Diving deeper into the patent data, peaks in the Services landscape map can be linked to more specific technologies. The peak highlighted in green and corresponding to the prominent keyword "STACK," can be linked to patented inventions related to set-top-box methods. The peak highlighted in blue and corresponding to the prominent keyword "PROVIDER," can be linked to patented inventions related to multimedia operating methods. The peak highlighted in yellow and corresponding to the second-level keywords "Line, Generation, and Precision clock," can be linked to patented inventions related to seismic data acquisition systems and high power radiation pulse generation. Finally, the peak highlighted in red and corresponding to the prominent phrase "COMPUTER SIMULATION," can be linked to patented inventions that are in the field of research of visual simulation of damage and night vision display enhancements.

Innovation and Collaboration by Sector

The Canadian space sector is comprised of six sectors of activity. A combination of publicly available information and survey data allowed for the categorization of Canadian organizations into the six sectors are as follows:

1. Navigation — The development and use of satellites for localization, positioning and timing services.
2. Satellite Communication (Satcom) — The development and use of satellites to send signals to Earth for the purpose of fixed or mobile telecommunications services and broadcasting.
3. Earth Observation (EO) — The development and use of satellites to observe the Earth for a number of purposes such as resource management, disaster assessment, and security and defence.
4. Space Exploration — The development and use of manned and unmanned spacecraft (probes, rovers) to investigate the reaches of the universe beyond Earth's atmosphere (e.g. the Moon, other planets, asteroids).
5. Space Science — The various scientific fields that relate to space flight or any phenomena occurring in space or on other planets (e.g. astrophysics, planetary science, space-related life science).
6. Other — Generic technologies or components that are not destined for use on a specific space system or for a specific space application. Any other activity that may not fit into the above definitions.

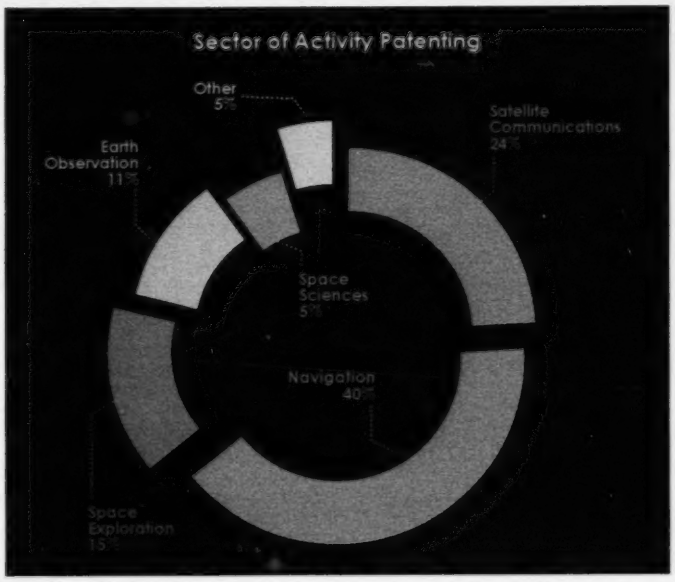

Figure 22: Sector of Activity Patenting

Organizations were categorized according to the amount of activity they perform in any given sector and multiplied by the number of patented inventions produced to provide a weighting for the amount of patent activity being carried out by each organization (Figure 22). Organizations linked to Navigation tend to patent the most (40%), followed by Satellite Communications (24%), Space Exploration (15%), Earth Observation (11%), Space Science (5%) and Other (5%).

Patent Landscape Maps

To dive deeper into the patent data, the report categorizes keywords by sector of activity. The data can then be presented in a landscape map. As noted previously, the use of the keywords presented in the map along with the most common IPC codes found in the patents, allow for the identification of various technological areas under development in the sector. Note that many keywords are ubiquitous and would be found in other industries and technologies. For this reason the space-specific keywords found in the landscape map are more useful. More widely-used keywords could then be applied to further refine the patent search. The opaque or less-visible keywords would provide a second level of detail. The intention is to facilitate exploration of the patent data by those interested in the technology or industry.

In Satellite Communications, 114 patented inventions were identified, with the prominent keywords being "DIFFRACTION", "WRITE", "GENERATOR", "INTERNET", "COMPENSATION", "TENSION", "SURVEILLANCE", "WAVE ELECTRODE", "ADAPT" and "ORBIT". These keywords are quite ubiquitous; diving deeper with more space-specific keywords such as orbital or Mach-zehnder would help refine the search. It is not surprising that the space sector that is linked to communications would have significant overlap with non-space sectors and would therefore have many widely-used keywords. Top IPC codes in the Satellite Communications segment include the following: G02B (Optical Elements, Systems, or Apparatus), H04B (Transmission), H04N (Pictorial Communication), H04L (Transmission of Digital Information), and H04W (Wireless Communication Networks).

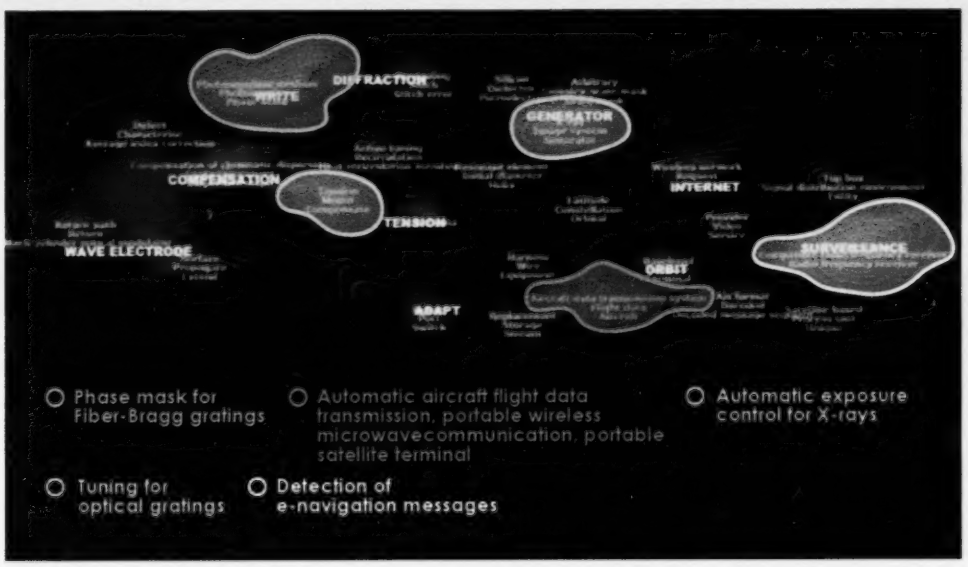

Figure 23: Canadian patented inventions in Satellite Communications Sector (114 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure23.

Taking this landscape map and analyzing the patent data a little further, some key technologies become apparent. Listed in the legend below the map, and corresponding to the peaks that are highlighted in colour, the key technologies associated with each peak can be found. The peak highlighted in green and corresponding to the second-level keywords "Tension, Mount, and Compensate," can be linked to patented inventions in the field of research related to tuning for optical gratings. The peak highlighted in orange corresponding to the prominent keyword "WRITE," can be linked to patented inventions related to Phase mask for Fiber-Bragg gratings. The peak highlighted in blue and corresponding to the prominent keyword "GENERATOR," can be linked to patented inventions related to automatic exposure control for X-rays. The peak highlighted in yellow and corresponding to the prominent keyword "SURVEILLANCE," can be linked to patented inventions related to the detection of e-navigation messages. Finally, the peak highlighted in red and corresponding to the second-level keywords "Aircraft data transmission system, Flight data, and Aircraft," can be linked to patented inventions related to automatic aircraft flight data transmission, portable wireless microwave communication, and portable satellite terminals.

In the Navigation Sector, 187 patented inventions were identified, with the prominent keywords being the following: "EXCLUSION", "CONTOUR", "PITCH ANGLE", "RADIATE", "INS POSITION", "KALMAN", "PREDICT", "SHIFT", "COMPUTER MEMORY", "RIGID", and "MANAGEMENT". While still containing a number of ubiquitous keywords, the navigation sector landscape map does contain keywords that are more space-specific; especially at the second level. Top IPC codes in the Navigation Sector segment include the following: G01S (Radio Direction Finding), G01C (Measuring Distances, Levels or Bearings), G05D (Systems Controlling Non-Electric Vehicles), G08G (Traffic Control Systems), and H04B (Transmission).

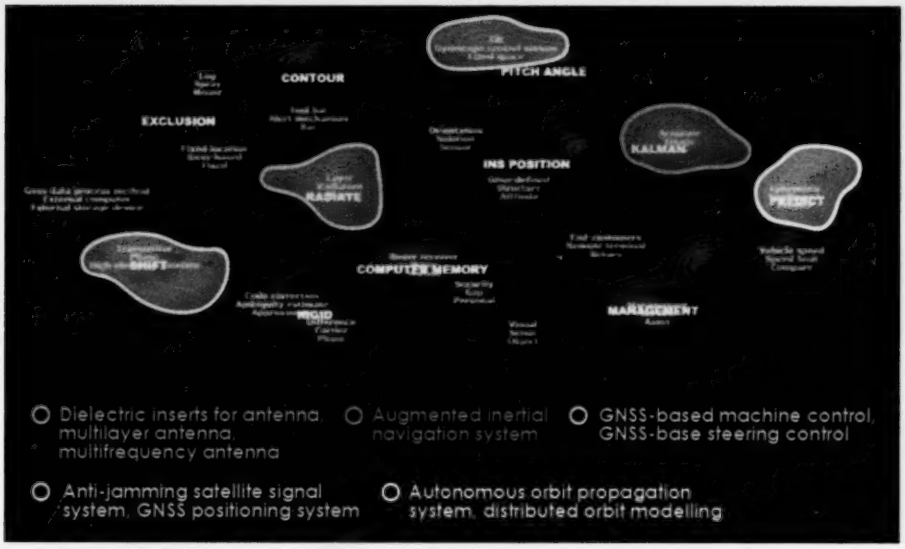

Figure 24: Canadian patented inventions in the Navigation Sector (187 patented inventions)
This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure24.

Diving deeper into the patent data, peaks in the Navigation Sector landscape map can be linked to more specific technologies that are identified in the legend below the map and that correspond to the coloured areas on the landscape map. The peak highlighted in green and corresponding to the prominent keyword "SHIFT," can be linked to patented inventions related to anti-jamming satellite signal systems, and GNSS positioning systems. The peak highlighted in orange and corresponding to the prominent keyword "RADIATE," can be linked to patented inventions related to technologies used in dielectric inserts for antennas, multilayer antennas, and multi-frequency antennas. The peak highlighted in blue and corresponding to the second-level keywords "Tilt, Gyroscope control system, and Fixed space" can be linked patented inventions related to GNSS-based machine controls and GNSS-base steering controls. The peak highlighted in yellow and corresponding to the prominent keyword "PREDICT," can be linked to patented inventions related to autonomous orbit propagation systems and distributed orbit modelling. Finally, the peak highlighted in red and corresponding to the prominent keyword "KALMAN," can be linked to patented inventions related to augmented inertial navigation systems.

In the Space Exploration Sector, 68 patented inventions were identified, including the following prominent keywords: "MAGNETIC", "COMBUSTION", "REFLECT", "BIOLOGICAL", "CHASSIS" and "IMAGE". Again these keywords are ubiquitous. However, by looking at the second-level keywords it can be seen that some of the technology is related to rockets (combustion, seal, thrust, space shuttle). The use of these keywords with the appropriate IPC codes would facilitate the identification of patented inventions related to space exploration. Top IPC codes in Space Exploration Sector segment include the following: G06F (Electrical Digital Data Processing), G06T (Image Data Processing), F02K (Jet-Propulsion Plants), B64G (Cosmonautics), and G01S (Radio Direction Finding).

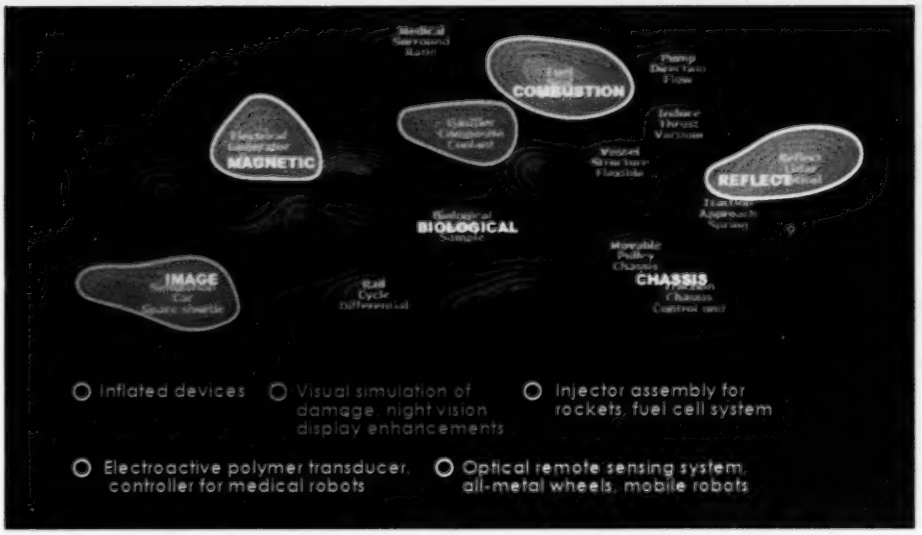

Figure 25: Canadian patented inventions in the Space Exploration Sector (68 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure25.

Taking this landscape map and analyzing the patent data a little further, some key technologies become apparent. Listed in the legend below the map, and corresponding to the peaks that are highlighted in colour, the key technologies associated with each peak can be found. The peak highlighted in green and corresponding to the prominent keyword "MAGNETIC," can be linked to patented inventions for technologies used in electroactive polymer transducers and controllers for medical robots. The peak highlighted in orange corresponding to the second-level keywords "Gasifier, Composite, and Coolant," can be linked to patented inventions related to inflated devices. The peak highlighted in blue and corresponding to the prominent keyword "COMBUSTION," can be linked to patented inventions related to injector assembly for rockets and fuel cell systems. The peak highlighted in yellow and corresponding to the prominent keyword "REFLECT," can be linked to patented inventions related to optical remote sensing system, all-metal wheels, and mobile robots. Finally, the peak highlighted in red and corresponding to the prominent keyword "IMAGE," can be linked to patented inventions related to visual simulation of damage and night vision display enhancements.

In the Earth Observation Sector, 50 patented inventions were identified, with the prominent keywords being the following: "APERTURE RADAR", "PRESENTATION", "VALVE", "CLIENT" and "COMMON". These keywords are ubiquitous. By looking at the second-level keywords it can be seen that some of the technology is related to positioning satellites and taking images (rotate, interferometer and monitor). The use of these with the appropriate IPC codes would facilitate the identification of patented inventions related to Earth Observation. Top IPC codes in the Earth Observation Sector segment include the following: B64G (Cosmonautics), G01S (Radio Direction Finding), G06F (Electrical Digital Data Processing), H01Q (Antennas), and B25J (Manipulators).

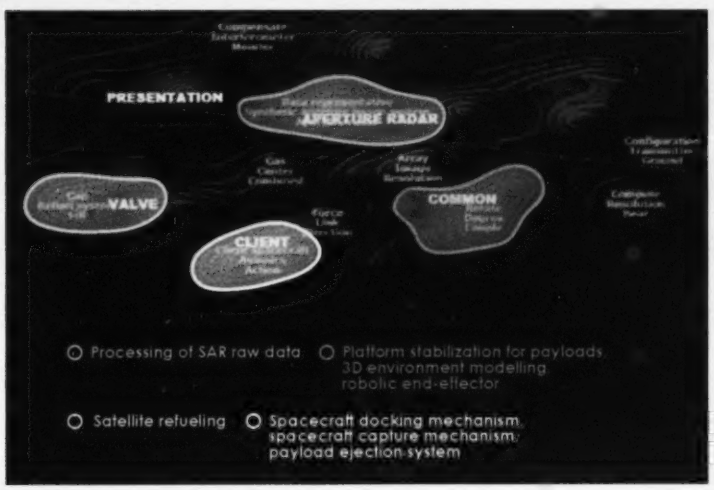

Figure 26: Canadian patented inventions in the Earth Observation Sector (50 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure26.

Diving deeper into the patent data, peaks in the Earth Observation Sector landscape map can be linked to more specific technologies that are identified in the legend below the map and that correspond to the coloured areas on the landscape map. The peak highlighted in green and corresponding to the prominent keyword "VALVE," can be linked to patented inventions related to satellite refueling. The peak highlighted in orange and corresponding to the prominent phrase "APERATURE RADAR," can be linked to patented inventions in the field of research of processing of SAR raw data. The peak highlighted in yellow and

corresponding to the prominent keyword "CLIENT," can be linked to patented inventions related to spacecraft docking mechanisms, spacecraft capture mechanisms, and payload ejection systems. Finally, the peak highlighted in red and corresponding to the prominent keyword "COMMON," can be linked to patented inventions related to platform stabilization for payloads, 3D environment modelling, and robotic end-effectors.

In the Space Sciences Sector, 21 patented inventions were identified, with the prominent keywords being the following: "PARAMETER", "CONVERT", "PLATFORM" and "NIGHT". These keywords are perhaps the most ubiquitous. By looking at the second-level keywords it can be seen that the technology is very much science-related and it may still be difficult to identify the space-specific patents. For this reason the use of appropriate IPC codes would be necessary in the identification of patented inventions related to the Space Sciences Sector. Top IPC codes in the Space Sciences Sector include the following: H02J (Circuit Systems for Electrical Power), F21V (Features of Lighting Devices), H02G (Installation of Electrical Power), G01T (Measurement of Nuclear or X-Radiation), and F21S (Non-Portable Lighting Devices).

Taking this landscape map and analyzing the patent data a little further, some key technologies become apparent. Listed in the legend below the map, and corresponding to the peaks that are highlighted in colour, the key technologies associated with each peak can be found. The peak highlighted in green and corresponding to the prominent keyword "NIGHT," can be linked to patented inventions involving technologies related to configurable safety light receptacles. The peak highlighted in orange and corresponding to the second-level keywords "Geologic, Geologic image, and High precision clock," can be linked to patented inventions in the field of research of seismic data acquisition systems, wireless inductive charging, and space elevators. The peak highlighted in yellow and corresponding to the prominent keyword "PARAMETER," can be linked to patented inventions related to data sensor validation systems. Finally, the peak highlighted in red and corresponding to the second-level keywords "Substrate, Emission, and Spectroscopy," can be linked to patented inventions related to neutron detectors.

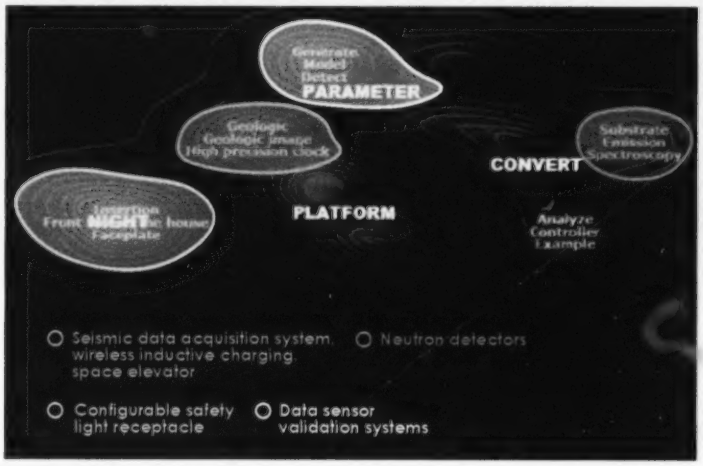

Figure 27: Canadian patented inventions in the Space Sciences Sector (21 patented inventions) This image is available through our website as a full scale version: http://ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr04393.html#figure27.

CONCLUSION

This report is a collaborative effort between the CSA and CIPO that examines patent and economic activity in the space sector. It explores the use of patented inventions as a proxy for measuring innovation and highlights the methodology used to develop a robust patent search strategy for the space sector. While patent activity for space technologies is not as prevalent as in other manufacturing or technology sectors, global patent filing in the space sector has consistently grown over the last 40 years and global revenues have increased by more than 70% in the last 10 years.

This robust patent search strategy produced a result set that had 86,000 patented inventions linked to the space sector globally, of which 1,200 involved a Canadian firm, government, academia, or research institution. Applying the OECD's Revealed Technological Advantage index, it was shown that Canada had a technological advantage in the space sector based on patent activity. This could imply that Canada has more influence internationally than its size would suggest.

Using data from the CSA's annual survey of the space sector, the global data set was refined to identify organizations that were involved in the Canadian space sector resulting in a subset of 128 Canadian organizations and 493 patented inventions. The analysis of this dataset showed that patented inventions by Canadians in the space sector have shifted from primarily being produced in the upstream segment in the late 1990's to a majority of patented inventions in the Canadian space sector now being produced in the downstream segment, which is consistent with the global trend. Although the larger space actors dominate when it comes to generating revenue and R&D expenditures, SMEs play a significant role in filing patents. SMEs accounted for 83% of the organizations filing patented inventions and 83% of the overall patented inventions in the Canadian space sector; yet, SMEs only accounted for 30% of the revenue and 30% of R&D expenditures in the Canadian space sector.

Patent landscape maps are used in this report to help identify keywords, IPC codes, and key technologies being developed in the Canadian space sector. The patent landscape maps were further broken down by value-chain segment and sector of activity in Canada. This information helps present the research being undertaken in the Canadian space sector, highlighting the associated keywords, IPC codes, and niche areas of technology. From a technology standpoint, the three main IPC codes associated with worldwide patented inventions in the space sector include the following: Radio Direction-Finding (G01S), Traffic Control Systems (G08G), and Cosmonautics, Vehicles or Equipment (B64G). Canadian organizations also file patents in these technology areas; however, most of their patented inventions are classified under the following technologies: G01S (Radio Direction Finding), G01C (Measuring Distances, Levels or Bearings), and H04B (Transmission).

The patent analysis was also useful in revealing five large organizational clusters of space sector activity located in the Greater Toronto Area, Montreal, Vancouver, Calgary and Ottawa. Organizations belonging to these clusters potentially benefit, simply as a result of their location, from increased productivity, faster innovation through collaboration and the creation of small organizations to cater to the niche needs of this industry.

Combining the CSA's annual space survey data with patent data resulted in multiple positive relationships being found. These included a relationship between the number of R&D employees per organization and annual patented inventions, a relationship between revenue and R&D expenditures, a relationship between revenue and R&D employees, a relationship between R&D expenditures and R&D employees, and a relationship between R&D expenditures and annual patented inventions.

Finally, a link can be made between the research in this report and Innovation, Science and Economic Development Canada's mandate that includes promoting innovation and science, supporting the commercialization of more research and ideas, helping small organizations grow through innovation, and supporting scientific research and the integration of scientific considerations in our investment and policy choices.[xxii] This report presents patent activity in the Canadian space sector over time and identifies niche areas of space technology being developed in Canada. We are hopeful that this report will be used as a launching pad for more in-depth research into patenting activity as it relates to targeted space technologies.

APPENDIX A – REGRESSION RESULTS

	Dependent Variable Annual Patented Inventions		Dependent Variable Revenue (Constant)
R&D Expenditures	0.197**	Annual Patented Inventions	0.109*
	(0.0854)		(0.0602)
		US GDP	78.43
			(65.3)
Constant	-3.375**	Constant	1.948
	(1.468)		(1.800)
R-Square		R-Square	
Within	0.0727	Within	0.0409
Between	0.1688	Between	0.1571
Overall	0.1925	Overall	0.037
Observations	235	Observations	309
Number of Organizations	31	Number of Organizations	32

*** p<0.01, ** p<0.05, * p<0.1
Robust standard errors in parentheses
Note that year dummies are included in the models

APPENDIX B – REVEALED TECHNOLOGICAL ADVANTAGE

Revealed Technological Advantage

In order to gain a better understanding of Canada's strengths in space technology research, we use the Revealed Technological Advantage (RTA) index, which was developed by the OECD and uses patenting intensity to allow for industries to be compared between countries of different sizes on a relative basis. The index is calculated as a correction for the absolute numbers of patented inventions in order to account for the fact that some countries file more patent applications than others in all fields of technology. In this report the RTA index is used to determine where Canadians have a comparative advantage over competitors.

The formula used to calculate the RTA is as follows:

$$RTA = \frac{\left({}^{(P_{i,t})}/_{(\sum_t P_{i,t})} \right)}{\left({}^{(\sum_i P_{i,t})}/_{(\sum_i \sum_t P_{i,t})} \right)}$$

Numerator
The total patented inventions for a technology category *t* in country *i* divided by all patented inventions for country *i*. This is done by summing across all technology categories, or *t*'s.

Denominator
The total patented inventions for a technology category *t* in all countries divided by the sum of patented inventions for all technologies and all countries. This is done by summing across all countries, or *i*'s for the *t* of interest, then dividing by the sum of these for all technology categories, or *t*'s.

Where *P* represents patents

An RTA greater than one suggests that the economy has a relative specialization in a particular field while an RTA lower than one suggests the opposite. An RTA equal to one is indicative that an economy's share of patents in that particular field equals its share in all fields, and therefore is not specialized.[xxii]

Note that the total number of patented inventions for Canada and for the world is based on foreign-oriented patent family data from the World Intellectual Property Office (WIPO) database. The reason the WIPO data was used is due to limitations in the size of extraction when using Derwent Innovation.

[i]https://science.howstuffworks.com/innovation/inventions/top-5-nasa-inventions3.htm and https://list25.com/25-coolest-nasa-discoveries-that-changed-your-life/

[ii]5 Canadian space inventions (that aren't the Canadarm) http://www.macleans.ca/society/life/5-canadian space-inventions-that-arent-the-canadarm/

[iii]The Space Economy at a Glance 2014 (OECD)

[iv]CSA - State of the Canadian Space Sector, OECD Space Economy at a Glance 2014

[v]Hanel, Petr, (2008). "The Use of Intellectual Property Rights and Innovation by Manufacturing Firms in Canada," Economics of Innovation and New Technology 17(4), 285-309.

[vi]2014 Survey on Financing and Growth of Small and Medium Enterprises, ISED and Statistics Canada

[vii]Baldwin, John R. and Gellatly, Guy (2006). "Innovation Capabilities: The Knowledge Capital Behind the Survival and Growth of Firms," The Canadian Economy in Transition Research Paper Series, Statistics Canada

[viii]Dernis, H. and D. Guellec. 2001. Using patent counts for cross-country comparisons of technology output. STI mimeo, OECD.

[ix]Kleinknecht, Alfred, Van Montfort, Kees and Brouwew, Erik, (2002). "The Non-Trivial Choice Between Innovation Indicators" Economics of Innovation and New Technology 11(2), 109-121.

[x]Comprehensive Socio-Economic Impact Assessment of the Canadian Space Sector

[xi]The Space Foundation – *Summary of the Space Report;* information on the international space industry 2005-2015.

[xii]The revenue presented does not include broadcasting revenue.

[xiii]State of the Canadian Space Sector 2014-2015

[xiv]R&D intensity is Manufacturing BERD/Manufacturing Direct Contribution to GDP

[xv]State of the Canadian Space Sector 2015

[xvi]2014 Survey on Financing and Growth of Small and Medium Enterprises, ISED and Statistics Canada

[xvii]The Space Economy at a Glance 2014 (OECD)

[xviii]Eight Great Technologies: Satellites – A patent overview (UKIPO)

[xix]https://www.mita.gov.mt/en/DigitalOutReach/poolingforclusters/Pages/Benefits-of-Clusters.aspx

[xx]Space and Innovation 2016

[xxi]https://www.space.com/39899-space-robotic-arm-inspires-surgery-tool.html

[xxii]Innovation, Science and Economic Development Canada, 2017-18 Departmental Plan https://www.ic.gc.ca/eic/site/017.nsf/vwapj/2017-18-ISED-DepartmentalPlan-Final-EN.pdf/$file/2017-18-ISED-DepartmentalPlan-Final-EN.pdf

[xxiii]National research university higher school of economics (PDF), https://www.hse.ru/data/2013/04/10/1297571825/09STI2013.pdf